

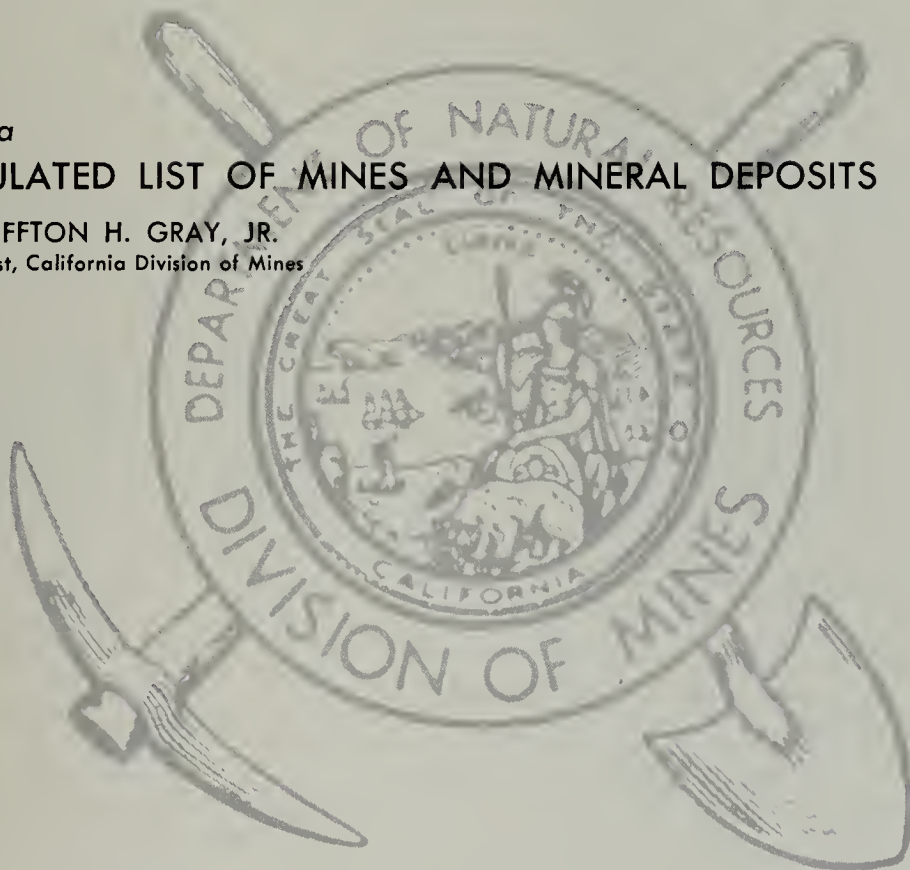
GEOLOGY OF THE SAN BERNARDINO MOUNTAINS NORTH OF BIG BEAR LAKE, CALIFORNIA

By JAMES FRANK RICHMOND

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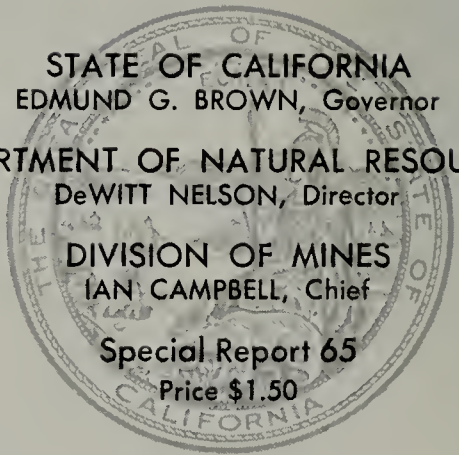
With a
TABULATED LIST OF MINES AND MINERAL DEPOSITS

By CLIFFTON H. GRAY, JR.
Geologist, California Division of Mines



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The seal of the State of California is visible in the background of the text. It is a circular emblem with the words "EUREKA" and "CALIFORNIA" at the top and "1849" at the bottom. The center features a landscape with a grizzly bear, a miner, and a ship.

CONTENTS

OUTLINE OF REPORT

	Page		Page
Abstract	7	General character	35
Introduction	9	Petrography	35
Geologic setting and plan of work	10	Interpretation	36
General geology and petrology	11	Age	36
Pre-batholithic sedimentary rocks	11	Biotite quartz monzonite	36
Chicopee Canyon formation of pre-Mississippian age	11	Distribution	36
Name and distribution	11	General character	37
Lithology and original internal structure	11	Petrography	38
Thickness	12	Origin of the biotite quartz monzonite	39
Conditions of sedimentation	12	Age	39
Age and correlation	12	Granite porphyry	39
Structural relations and age of deformation	12	Distribution	39
Contact metamorphism	13	General character	39
Petrography of the quartzites and hornfelses	13	Petrography	40
Metamorphic facies	14	Age	41
Furnace formation of Carboniferous age	15	Biotite quartz monzonite of migmatitic origin	41
Name and distribution	15	Distribution	41
Lithology and internal structure	15	General character	41
Thickness	17	Petrography	43
Conditions of sedimentation	17	Relation to other granitic rocks	44
Age and correlation	17	Volcanic origin of the host rocks of the migmatites	44
Structural relations and age of deformation	18	Age and correlation	44
Pre-batholithic alteration	19	Post-batholithic sedimentary rocks	45
Contact metamorphism	20	Old Woman sandstone	45
Petrography of the hornfelses	21	Distribution and structural relations	45
Additive contact metamorphism	22	General character	45
Metamorphic facies	23	Correlation and age	45
The development of the igneous rocks	24	Terrace deposits	46
Volcanic rocks and their relation to the batholith	25	Distribution and structural relations	46
Distribution	25	Origin and age	46
General character	25	Tahs breccia	46
Petrography	26	Alluvium	46
Mode of occurrence	28	Older alluvium	46
Age and correlation	28	Recent alluvium	47
Gabbro and diorite	28	Structure	47
Distribution	28	Pre-Tertiary structure	47
General character	28	Late Cenozoic structure	47
Petrography	28	Thrust faults	48
Probable origin of the gabbro and diorite	29	High-angle faults	49
Age and correlation	29	Landslides	50
Tonalite porphyry	29	Deformation in adjacent areas	50
Distribution	29	Elevation of the San Bernardino Mountains	50
General character	29	Sketch outline of geologic history	50
Petrography	29	Mineral resources	51
Interpretation and age	30	Introduction	51
Hornblende quartz monzonite	30	Metals	51
Distribution	30	Lode gold	51
General character	31	Placer gold	51
Petrography	33	Iron	54
Structural features related to origin	34	Lead-zinc-silver	54
Age	35	Manganese	54
Granite cataclasite	35	Tungsten	54
Distribution	35		

	Page
Age of mineralization.....	54
Nonmetallic minerals	56
Clay	56
Carbonate rocks	56
References cited	57
Tabulated list of mines and mineral deposits in an area of the San Bernardino Mountains north of Big Bear Lake, San Bernardino County, by Clifton H. Gray, Jr.....	59

ILLUSTRATIONS

Plate 1. Geologic map and sections of San Bernardino Mountains north of Big Bear Lake.....In pocket

Figure 1. Index map showing location of area studied.....	8
2. Photo showing the north scarp of the San Bernardino Mountains	9
3. Photo showing view north across Holcomb Valley....	10
4. Photo showing view south across Holcomb Valley....	10
5. Photo showing cross-bedded quartzite in lower member of Chicopee Canyon formation.....	12
6. Photo showing massive white quartzite in upper member of Chicopee Canyon formation.....	12
7. Photomicrograph of calc-silicate hornfels, Chicopee Canyon formation	13
8. Photomicrograph of pelitic hornfels, Chicopee Canyon formation	13
9. Photo showing massive calcite and dolomitic marble, Furnace formation, west side of Furnace Canyon....	15
10. Photo showing dolomitic marble grading upward to dolomite, Furnace formation, east side of lower Furnace Canyon	16
11. Photo showing <i>Caninia</i> -type corals at locality 5, Furnace formation	16
12. Photo showing hand specimen of dolomitized limestone, Furnace formation.....	16
13. Photomicrograph of brucite in dedolomitized magnesian limestone, Furnace formation.....	17
14. Photomicrograph of granoblastic tremolite in dolomite, Furnace formation	17
15. Photomicrograph of white chlorite in quartz-calcite-tremolite-diopside hornfels, Furnace formation....	18
16. Photomicrograph of chlorite-dolomite-forsterite hornfels, Furnace formation.....	18
17. Photo showing micaceous siltstone lens, Furnace formation	19
18. Photo showing hematite skarn at Desert View mine....	19
19. Detail of figure 18, Furnace formation.....	22
20. Photomicrograph of serpentized forsterite-calcite hornfels, Furnace formation.....	23
21. Photo showing Furnace marble screen separating granite porphyry and quartz latite porphyry.....	24
22. Photo showing banded quartz latite porphyry, Coyote Canyon	24
23. Photo showing hand specimen of banded quartz latite porphyry	25
24. Photo showing quartz latite porphyry intruding Furnace marble	26
25. Photomicrograph of banded quartz latite porphyry....	26
26. Photomicrograph of quartz latite tuff.....	27
27. Photomicrograph of intergrowth of hornblende and labradorite in diorite.....	27
28. Photo showing exposure of tonalite porphyry at head of Poligue Canyon.....	30
29. Photomicrograph of zoned andesine phenocrysts rimmed with orthoclase in tonalite porphyry.....	30

	Page
30. Photomicrograph of biotite replacing hornblende in tonalite porphyry	30
31. Photo showing exposure of hornblende quartz monzonite west of Holcomb Creek.....	31
32. Photo showing gneissic hornblende quartz monzonite	31
33. Photo showing hornblende quartz monzonite overlying mylonite	31
34. Photo showing recrystallized mylonite west of Greenlead Camp	32
35. Photo showing rhythmic layering, ridge west of Little Bear Peak	33
36. Photo showing lenticular pegmatite veins cut by epidote veinlets	33
37. Photomicrograph of fractures filled with deuterite hornblende	34
38. Photomicrograph of mylonite showing porphyroclastic texture	35
39. Photomicrograph of garnet porphyroblast in blastomylonite	35
40. Photo showing exposure of granite cataclasite in west wall of Silver Canyon.....	36
41. Photomicrograph showing hypidiomorphic granular texture, granite cataclasite.....	36
42. Photomicrograph of hematite pseudomorph after pyrite	36
43. Photo showing jointing in biotite quartz monzonite near Grout Creek west of Fawnskin.....	37
44. Photo showing exposure of biotite quartz monzonite in wall of Silver Canyon.....	37
45. Photomicrograph of oligoclase replaced by microperthite	38
46. Photomicrograph of micrographic texture.....	39
47. Photomicrograph of oligoclase phenocrysts rimmed with microcline	40
48. Photomicrograph of quartz replacing oligoclase.....	40
49. Photo showing pre-biotite quartz monzonite skialiths	41
50. Photo showing migmatite between Dry and Deep Canyons	41
51. Photo showing replacement dikes of biotite quartz monzonite	42
52. Photo showing intrusion breccia, west side of Deep Canyon	43
53. Photomicrograph of hornfelsic groundmass in migmatite	43
54. Photo showing sorted terrace deposits.....	44
55. Photo showing talus breccia in lower Poligue Canyon	45
56. Structure sections and outline map of main structural features in the area studied.....	47
57. Photo showing granite cataclasite thrust over Old Woman sandstone	48
58. Photo showing topographic expression between Crystal Creek thrust and Wild Rose fault.....	48
59. Photo showing recumbent fold axis in cherty black marble	49
60. Photo showing marble roof pendant, west side of Furnace Canyon	49
61. Economic map of San Bernardino Mountains north of Big Bear Lake.....	52
62. Photo showing idle Harvey K mine, east side of Upper Holcomb Valley.....	53
63. Panorama of Upper Holcomb Valley gold placer area	53
64. Photo showing the Garvey Placer, Upper Holcomb Valley	54
65. Photo showing typical occurrence of the gold-bearing "bench gravel" in Upper Holcomb Valley.....	55

	Page
66. Photo showing gold-bearing "bench gravel" in Upper Holcomb Valley	55
67. Photo showing gold-bearing "bench gravel" in Upper Holcomb Valley, Slap Jack Placer.....	55
68. Photo showing plant No. 2 operation site of the Holcomb Valley Placer Company, 1940.....	55
69. Photo showing No. 1 plant, Holcomb Valley Placer Company, a typical processing installation, 1940..	56

	Page
70. Photo showing placer tailings in Upper Holcomb Valley, 1956	56
71. Photo showing Cushenbury limestone quarry of Permanente Cement Company.....	56
72. Photo showing Cushenbury plant of Permanente Cement Company	57
Table 1. Chemical analyses of carbonate rocks from the Furnace formation	20

GEOLOGY OF THE SAN BERNARDINO MOUNTAINS NORTH OF BIG BEAR LAKE, CALIFORNIA *

By JAMES FRANK RICHMOND **

ABSTRACT

The San Bernardino Mountains are a highland region in southern California about 100 miles east of Los Angeles. The area mapped for this report consists of about 50 square miles north of Big Bear Lake; it covers the north-central part of the mountains and the slope that falls steeply north to the Mojave Desert. Formations and structure are shown on a topographic map and in structure sections on the scale 1:24000. The topographic base is enlarged from the southwestern part of the U. S. Geological Survey Lucerne Valley quadrangle.

The rocks are grouped in three main units: (1) Carboniferous and older sedimentary rocks, which cover about one-fourth of the area; (2) volcanic and plutonic rocks of Mesozoic age, exposed over more than half the area; and (3) late Cenozoic elastic sedimentary rocks which cover the remainder.

Metamorphosed sedimentary rocks, older than the igneous rocks, occur in two formations. The Chicopee Canyon formation of pre-Carboniferous age is predominantly quartzite and has a minimum thickness of 1320 feet. It is overlain in apparent conformity by the Furnace formation, which consists chiefly of calcitic and dolomitic marbles and which may be 5000 feet thick. Probably at least 1000 feet of the Furnace formation is of Mississippian age; the remainder may be in part of Pennsylvanian age. The Furnace formation was dolomitized, locally silicified, and folded prior to the intrusion of the igneous rocks. The Chicopee Canyon formation shared this deformation. Static metamorphism resulted from the granitic intrusions; foliated rocks were not developed and the northwesterly trend of the pre-intrusive folds was preserved. Contact metamorphism produced low- and medium-grade hornfels in both of the older sedimentary formations. In the Furnace formation contact-metamorphic effects included marmorization and dedolomitization, and contact metasomatism at granitic contacts produced thin zones of tectite and skarn.

Volcanic eruptions of Triassic(?) age preceded intrusions of the Jura-Cretaceous plutonic series. Quartz latite porphyry, quartz latite tuff, and trachy-andesite are preserved partly in dikes in Furnace marble and more extensively as migmatites formed by reaction with biotite quartz monzonite magma or its emanations.

The plutonic sequence and allied intrusions are part of a composite batholith widely exposed in the San Bernardino Mountains and southeastern Mojave Desert. The rocks comprised in the batholith have an exposed thickness of 4000 feet in the area studied, where they consist of small bodies of gabbro, diorite, and tonalite porphyry, and larger masses of hornblende quartz monzonite, biotite quartz monzonite, and granite porphyry. Hornblende quartz monzonite was in part forcibly injected in older sedimentary rocks, whereas biotite quartz monzonite, the predominant rock of the batholith, was emplaced probably in the main by stopping. Most of the granitic rocks consolidated and differentiated from a magma, but biotite quartz monzonite was formed locally by replacement of Triassic(?) volcanic rocks.

The post-batholithic sedimentary rocks, of continental origin, include the Old Woman sandstone, a conglomeratic sandstone of Miocene-Pliocene age; terrace deposits and talus breccias of Pleistocene(?) age; and alluvium of two ages.

Late Cenozoic thrust-faulting along the range front produced cataclasis in the igneous rocks and minor sharp folds in the Furnace formation, and initiated higher relief which led to the accumulation of the terrace deposits and talus breccias. The terrace deposits have been uplifted along later high-angle faults.

The predominant trend and dip of faults and overturned folds reflect a long history of compressive stress from the west and southwest. Similar relations east and west of the mapped area suggest that the San Bernardino Mountains were uplifted mainly by thrust-faulting rather than by block-faulting.

* A condensation and partial revision of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Geology, in the School of Mineral Sciences, Stanford University, October 1954. Manuscript submitted to the Division of Mines for publication May 1955.

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Figure 1. Index map showing location of the area studied.

INTRODUCTION

Location and Accessibility of the Area. Portions of the southern Mojave Desert and the north central San Bernardino Mountains of southern California are shown on the 15-minute Lucerne Valley quadrangle. This paper deals chiefly with a mountainous area of about 60 square miles north of Big Bear Lake in the southwestern part of the quadrangle (index map, fig. 1). The principal canyons opening from the range front into the desert are accessible by poor roads from the Mojave Desert town of Lucerne Valley, 21 miles east of Victorville. The high country is best reached from Big Bear Lake by a system of secondary roads maintained by the U. S. Forest Service. Both the desert and mountain roads join State Highway 18 which skirts the area on the north, east, and south.

Topography. The dominant topographic feature of the area is the steep declivity that separates the undulating upland surface from the Mojave Desert to the north (fig. 2). In a horizontal distance of 2 or 3 miles, the precipitous slope drops about 3500 feet. At the range front alluvial fans of the principal canyons coalesce at a level of about 4500 feet and slope more gently northward to the floor of the desert.

In the highlands south of the range slope, two eastward-trending divides, separated by valleys, have nearly accordant summits. Summit peaks have maximum elevations of more than 8300 feet (figs. 3 and 4). The alternation of ridges and valleys forms a crenulated upland surface with a local relief of about 1500 feet. The drainage divide of the San Bernardino Mountains crosses Holcomb Valley, northernmost of the eastward-trending valleys. Drainage of lower Holcomb Valley is tributary to the Mojave River which flows northward to the Mojave Desert. Drainage of upper Holcomb Valley is tribu-

tary to the Santa Ana River by way of Bear Valley and Bear Creek, eventually reaching the Pacific Ocean to the southwest. Bear Valley is the southernmost of the eastward-trending valleys. It is dammed southwest of the quadrangle boundary, forming Big Bear Lake, which is a popular summer resort.

Climate and Vegetation. Most of the precipitation in the mountain area falls as snow during the winter months. The average annual precipitation in the Big Bear Lake area is about 40 inches; in the Mojave Desert north of the scarp, about 5 inches.

Except for the alluvial valleys, the mountains are heavily forested with Jeffrey pine, large junipers, and piñon. Where pines do not grow, slopes are thickly covered with mountain mahogany and manzanita. Small juniper trees which form the main cover on the north slope give way at the desert to Joshua trees, sagebrush, and cactus.

Field and Laboratory Work. Field work was done during June to September 1952, and April to September 1953. In open areas field mapping was done on aerial photos flown for the U. S. Geological Survey in 1945 (scale approx. 1:24000). In the forested areas a 1:24000 enlargement of the Lucerne Valley quadrangle (U. S. Geological Survey, 1948) was used. All data were finally transferred to the same enlargement which forms the geologic map (pl. 1) of this report. Laboratory work was carried on between periods of field work. This consisted chiefly of the study of 230 thin sections and of physical and chemical tests of the older sedimentary and igneous rocks.

Acknowledgments. Dr. Adolph Knopf and Dr. Robert R. Compton of Stanford University offered very helpful suggestions concerning the field and petrographic work. Dr. A. O. Woodford of Pomona College made available aerial photos of the Lucerne Valley quad-



Figure 2. The north scarp of the San Bernardino Mountains. View southeast from Lucerne Valley.



Figure 3. View north across Holcomb Valley from ridge between Holcomb Valley and Bear Valley.

range. Dr. Charles W. Merriam of the U. S. Geological Survey kindly identified several fossils from the Furnace formation. Mr. Robert Yerkes of the U. S. Geological Survey helped to prepare the photomicrographs used in this report. The California State Division of Mines arranged for partial chemical analyses of samples from the Furnace formation. Stanford University supplied research grants that are much appreciated.

Previous Geologic Work in the Area. The only published geologic map of the area north of Big Bear Lake is included in an excellent reconnaissance map of the 30-minute U. S. Geological Survey San Geronimo quadrangle by Vaughan (1922). Primarily a physiographic treatment, the work also delimited several igneous, sedimentary, and metamorphic units.

More recent work has been done in local areas of the Lucerne Valley quadrangle that lie to the east of the area mapped for the present report. Woodford and Harriss (1928) described the geology of Blackhawk Canyon in the southeastern part of the quadrangle. They reported fossils of Mississippian(?) age from the Furnace limestone at the head of Crystal Creek, gave chemical analyses of carbonate rocks exposed along the range scarp, and established the presence of low-angle reverse faults of late Tertiary or Quaternary age.

Guillou (1953) did detailed work on the limestones and quartzites in the Johnston Grade area north of Baldwin Lake. He redefined a part of the stratigraphic sequence established by Vaughan and recognized the Chicopee Canyon formation of pre-Carboniferous age. Guillou also demonstrated low-angle thrust-faulting and overturning in the Johnston Grade area.

Several of the formations described by Vaughan, Woodford and Harriss, and Guillou are recognized in the present report to occur in the southwestern part of the Lucerne Valley quadrangle.

GEOLOGIC SETTING AND PLAN OF WORK

Three distinct rock groups are recognized in the area north of Big Bear Lake. The oldest group consists of Carboniferous and pre-Carboniferous sedimentary rocks that underlie about a quarter of the mapped area. Some of these rocks experienced post-depositional alteration, and probably all of them were gently folded prior to the intrusion of igneous rocks which isolated them into dozens of roof pendants that range in size from outcrops too small to be shown on the geologic map, upward to masses that measure more than 2 miles across.

Volcanic rocks are regarded as the oldest of the second large group of rocks. Their emplacement was followed, after an unknown time interval, by a sequence of plutonic and allied intrusions that include gabbro and diorite, tonalite porphyry, hornblende quartz monzonite, biotite quartz monzonite, and granite porphyry. The plutonic and hypabyssal rocks are part of a composite batholith which is exposed over nearly half the area studied and underlies large parts of the adjacent San Bernardino Mountains and southeastern Mojave Desert.

If the volcanic rocks are of Triassic age, as appears probable, the earliest deformation of the older sedimentary rocks may have occurred at the close of the Paleozoic era. Absolute age determinations based on atomic disintegration in adjacent areas indicate that most of the granitic rocks had probably crystallized by middle Cretaceous time.

The third group of rocks, which underlies small areas, consists of clastic sedimentary deposits of late Cenozoic age. Their chief interest lies in the assistance they give in dating post-batholithic structural events.



Figure 4. View south across Holcomb Valley. At left, Bertho Peak (elev. 8198') cops ridge that separates Holcomb and Bear Valleys.

This paper describes the formations included in the three principal rock groups in order of decreasing age. Complex relationships in the first two groups make it desirable to emphasize individual rock units in the description of general geology and petrology. Discussions of diagenetic alteration, pre-batholithic deformation, structural relations, metamorphism, retrograde changes, and rock origins that would otherwise warrant separate headings are, therefore, developed as topics under formational headings. The pre-Tertiary structural history of the area is discussed, with emphasis on the late Cenozoic structural events that accompanied the rise of the San Bernardino Mountains. A sketch outline of the geologic history is also given herein.

GENERAL GEOLOGY AND PETROLOGY

Pre-Batholithic Sedimentary Rocks

The older sedimentary rocks are readily classified into two formations that have been recognized and partly described by earlier workers. There has been some disagreement in regard to the stratigraphy. In the area of the present report the rocks consist of an older series of impure quartzites that has a minimum thickness of 1320 feet, and a younger series of carbonate rocks that may have a thickness of more than 5000 feet. The two formations are not separated by a demonstrable unconformity. The age of the quartzite is not known, but the carbonates are in part of Mississippian age.

Chicopee Canyon Formation of Pre-Mississippian Age

Name and Distribution

The name "Chicopee formation" was proposed by Guillou (1953) for a series of metamorphosed quartzites lying beneath gray marble of the Furnace formation in the Johnston Grade area about 7 miles northeast of Delamar Mountain. The name "Chicopee formation" is pre-empted (Wilmarth, 1938, p. 428), and it is here proposed that the name be amended to Chicopee Canyon formation. Rocks very similar to those described by Guillou are poorly exposed in the same stratigraphic position beneath Furnace marble over an area of a square mile on the eastern and southeastern flanks of Delamar Mountain. The upper part of the Chicopee Canyon formation crops out also north of Bertha Peak.

Lithology and Original Internal Structure

Two members are recognized in the Chicopee Canyon formation. The lower member is intruded at the base by tonalite porphyry.

Lower Member. The rocks of this series have a minimum thickness of 1000 feet. Cross-bedded quartzites, thin-bedded quartzites, and micaceous quartzites are recognized. All three rock types occur throughout the lower member of the formation but they become progressively dominant upward in the order described.

The basal rocks consist chiefly of cross-bedded quartzites laminated light and dark gray. The thinner dark laminae, about 1 mm thick, are marked by concentrations of metamorphic biotite. The light-gray layers, from 4 to 5 mm thick, are composed chiefly of feldspar and quartz and contain less biotite than is found in the thin layers.

The layers are curved and stratigraphic sequences of 15 to 20 layers (comprising a thickness of 5 to 10 cm) are topped and truncated by other series of similar layers. The truncated layers are inclined at an angle of about 30° to the surface of truncation and have an apparent radius of curvature of from 20 to 50 cm. Often the surface of discontinuity can be traced completely around the outcrop (fig. 5).

Thin-bedded quartzites occur throughout the lower member but are most prominent in the middle part of the series. There thin-bedded quartzites are intercalated at 6- to 8-foot intervals with cross-bedded quartzite, lenses of massive white quartzite as much as 3 feet thick, micaceous quartzite, and rare thin pods of coarse marble. The thin-bedded quartzites are characterized by fine-grained texture and sharply defined straight bedding planes marked at intervals of 5 to 20 mm by thin layers of mafic minerals. The darker and thinner resistant layers contrast rather sharply with the greenish-white, less resistant layers in which quartz and feldspar are the most abundant minerals.

Medium-grained micaceous quartzites are predominant in the uppermost 300 feet of the series, where cross-bedded quartzites are rarely seen. Muscovite and coarse biotite at some places make up 30 percent of the rock. The soft, micaceous, dark-gray layers, 1 or 2 mm thick, are intertongued with somewhat thicker layers composed of feldspar and quartz.

In places crenulations exposed on micaceous bedding planes have periodic continuous crests spaced about 3 cm apart. They may represent ripple marks. Spoon-shaped dents of unknown origin, with mica flakes molded into them, are also exposed on some micaceous bedding planes. One or the other of these structures commonly gives the micaceous bedding planes a crumpled appearance.

Pegmatites locally intrude the cross-bedded and micaceous quartzites. They are not traceable to an igneous body. The largest single exposure, about 3 feet wide and 8 feet long, is lenticular. Much thinner pegmatite lenses intrude along bedding planes. Notably leucocratic, the pegmatites are composed chiefly of microcline, in part graphically intergrown with quartz.

Upper Member. Two distinctive, persistent units make up the upper member of the Chicopee Canyon formation. They consist of 370 feet of massive white quartzite overlain by 75 feet of andalusite-bearing rock.

The very resistant massive white quartzite is cut by a system of recemented joints. A typical outcrop consists of a jumbled array of oblong or angular talus blocks 3 feet or more in width (fig. 6). Rare and rather vague thin dark-brown stains, concordant with the dip of the underlying beds, suggest segregation of impurities along bedding planes during metamorphism. Irregular quartz grains, from 2 to 5 mm in diameter, give the rock a vitreous luster. Traces of iron oxide stain are common.

In outcrop the reddish-brown andalusite-bearing rock disintegrates readily into medium-grained sand. Even in fresh exposures the rock resembles a massive sandstone, and neither the granoblastic texture nor the presence of andalusite is apparent with a hand lens. Muscovite, biotite, and quartz are abundant.



Figure 5. Typical outcrop of cross-bedded quartzite in the lower member of the Chicopee Canyon formation, ridge east of Delamar Mountain.

Thickness

Two sections were measured with a tape across the best exposures of the Chicopee Canyon formation. A thick forest cover limits exposures to perhaps 15 percent of the area underlain by the quartzites. Thicknesses can therefore only be estimated semiquantitatively. One section was measured along the ridge due east of Delamar Mountain. The second measured section is a mile north-east of Fawnskin across the boundary of secs. 1 and 12, T. 2 N., R. 1 W. The sections indicate that the minimum thickness of the formation is 1320 feet. In each section the base of the formation is intruded by tonalite porphyry.

Measured sections and field observations also indicate that the massive white quartzite of the upper member of the Chicopee Canyon formation thickens to the north-east.

Conditions of Sedimentation

Internal structure and composition of the Chicopee Canyon formation suggest near-shore conditions of deposition for the most of the quartzite. Cross-bedded quartzite and relic ripple marks furnish evidence of current action during accumulation of the lower member. The massive white quartzite contains almost nothing but quartz, indicating that it is in part a residual product of intense chemical weathering. The high aluminum content, inferred from the abundance of andalusite at the top of the formation, suggests the former abundance of clay minerals. Relic structures that would help to explain the concentration of clay are absent. The clay may have been formed under marine conditions after deep subaerial weathering of micaceous sandy sediments.



Figure 6. Massive white quartzite in the upper member of the Chicopee Canyon formation.

Age and Correlation

No fossils were found in the Chicopee Canyon formation. Tops of beds established by truncated cross-bedding indicate that the strata are right side up across the measured sections. As the lower part of the overlying Furnace formation is Mississippian, the Chicopee Canyon formation is early Mississippian or pre-Mississippian in age.

Vaughan's map shows quartzites southeast of Delamar Mountain dipping beneath the Furnace limestone, but his references to the area state that the section is probably overturned (p. 356, 360, 394). Vaughan therefore assigned the quartzites to the Saragossa formation of post-Furnace age. The present work does not support this view. The quartzites in the mapped area are considered to be the equivalent of those in the Johnston Grade area where Guillou has mapped an estimated thickness of 2150 feet of quartzites beneath gray marble of the Furnace formation.

Structural Relations and Age of Deformation

The Chicopee Canyon quartzites are now exposed principally in a faulted, eroded anticline overturned to the northwest. Minor structures are imperfectly known because of poor exposures. Tonalite porphyry intrudes the base of the formation and is exposed in the center of the anticline. This relation indicates that the principal deformation of the quartzite was not later than the intrusion. Internal structures in the tonalite porphyry, later described, suggest that the intrusive rock is of post-tectonic age. Positive evidence is lacking as to the age of the principal folding. It is clear, however, that the Furnace formation, of Carboniferous age, was folded prior

to intrusion of the Triassic(?) volcanic rocks, and it is inferred that the Chicopee Canyon formation experienced its principal deformation at the same time.

The southwestern continuation of the anticline is not exposed as would be expected, and there is no demonstrable fault to account for this. Possibly the continuation of the sedimentary rocks was dropped downward during emplacement of the tonalite porphyry. The mapped faults are of post-batholithic age.

Contact Metamorphism

The excellent preservation of primary depositional structures and the lack of foliation show that stress was never effective in crushing the rocks, and that dynamothermal metamorphism was generally absent during the metamorphism of the rocks of the Chicopee Canyon formation. Crumpled and dented bedding planes in the more micaceous quartzites suggest only an incipient schistosity which may be masked by post-intrusive deformation. Relic structures that would indicate granulation were rarely seen in thin section although strain shadows and fractures in quartz xenoblasts suggest some post-recrystallization movement. It is concluded that recrystallization of the rocks was accomplished almost entirely by normal contact metamorphism. This term is used here to mean the general metamorphism which occurs around large igneous masses at comparatively low temperatures with little or no change in the bulk composition of the rock.

Petrography of the Quartzites and Hornfelses

The evidence of contact metamorphism is best seen in the microscopic features of the recrystallized rocks. Fifteen thin sections of the Chicopee Canyon formation were examined. Without exception these show some recrystallization and reconstitution of the component minerals.

The quartzites in the lower member of the formation show complex microscopic features. The fabric is commonly granoblastic. In general the rocks contain four principal minerals: quartz (50-75 percent), feldspar (5-rarely 30 percent), biotite (5-20 percent), and muscovite, including sericite (5-10 percent). Quartz shows a consistent xenoblastic habit in nearly all thin sections and a rather consistent grain size that rarely exceeds 5 mm. Microcline, microperthite, albite, oligoclase, and sodic andesine were found, although not all are present in any one quartzite. Calcic plagioclase is relatively rare. Albite twinning was observed only in oligoclase and andesine grains. Less abundant minerals in beds of the lower member are apatite, sphene, rutile, zircon, tourmaline, iron ore, and chlorite. The principal minerals vary in abundance in the three main quartzite facies of the lower member, but quartz is so predominant as to justify the field term of quartzite in the formation as a unit.

Hornfelses Derived from Cross-bedded Sandstones. The granoblastic fabric of these rocks is best shown by the sutured and interpenetrating contacts between adjacent quartz xenoblasts. Quartz makes up about 75 percent of the thin sections. The average specific gravity of

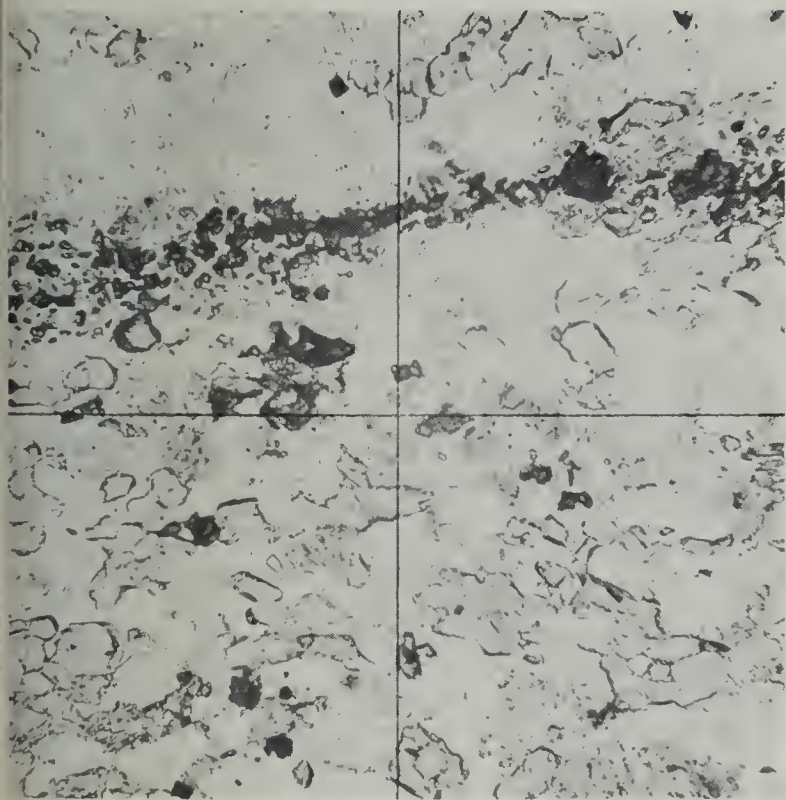


Figure 7. Photomicrograph. Sphene-diopside-hornblende-olbite-epidote calc-silicate hornfels of the Chicopee Canyon formation. Sphene forms the dark layer extending across slide. Hornblende (high relief) lies in mosaic of quartz and feldspar. Ordinary light, x 37.

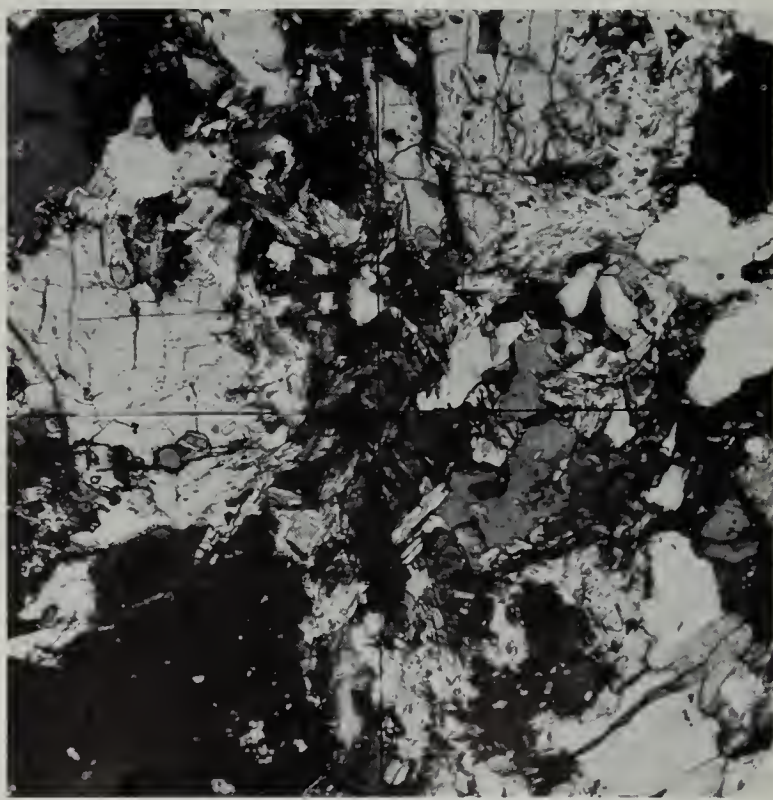


Figure 8. Photomicrograph. Muscovite-biotite-ondolusite-quartz-pelitic hornfels of the Chicopee Canyon formation. Xenomorphic ondolusite (note cleavage) is partly replaced by muscovite. Crossed nicols, x 33.

three specimens is 2.67. In a typical sample collected about 200 feet from the base of the section quartz grains average about 2 mm in diameter, but larger crystals are as much as 5 mm in diameter. The larger grains are commonly fractured and recemented. They usually show an uneven extinction and an optic angle of 2° - 4° . Minor amounts of oligoclase (An 25-28), determined by oil immersion technique, and microcline are interstitial to the quartz and rarely included within quartz. Small flakes of muscovite and olive-green biotite are interstitial to quartz. They are not molded around quartz; in a few places they lie across quartz boundaries. Zircon, rutile, and apatite are present as accessory minerals.

Hornfels Derived from Thin-bedded Arkosic Sandstones. In these rocks the feldspar content reaches a maximum of 30 percent. The bulk specific gravity averages 2.60. A sample collected about 800 feet above the base of the section contains a very fine-grained assemblage of amphibole, clinopyroxene, epidote, sphene, albite, microcline, and quartz. The heavy minerals are concentrated along relic bedding planes in layers as much as 1 mm thick in a groundmass mosaic of quartz, albite, and microcline. Sphene was found as a prominent layer 0.2 mm wide (fig. 7). In the same layer minute crystals of pale green hornblende partly replace rare clinopyroxene. The presence of clinopyroxene is considered to be in part related to an earlier dolomitic cement. Quartz and microcline, the predominant minerals, have a typical fine-grained mosaic structure.

Hornfels Derived from Micaceous Sandstones. The range in specific gravity of these quartzites (2.71 to 2.80) apparently reflects the variant content of micaceous minerals, which may form as much as 25 percent of some specimens. In a thin section from a specimen collected about 700 feet above the invaded base of the Chicopee Canyon formation, the paragenetic succession in the micaceous minerals may be sericite-muscovite-green biotite. The last stage is not clearly established. Brown biotite appears partly to replace earlier fresh green biotite. Less than half the clusters of sericite enclose sutured clumps of microcline that reach a maximum diameter of 5 mm. The more common fine-grained feldspar-quartz fabric shows relics of detrital origin, but the subrounded appearance of a few of the quartz and microcline grains could be due to post-recrystallization movement. Tourmaline is rarely present.

No feldspars were seen in the upper member of the Chicopee Canyon formation. The massive white quartzite at the base of the upper member contains almost nothing but quartz grains from 2 to 5 mm in diameter. Recrystallization is shown by the sutured crenulated contacts between the quartz grains, and post-crystallization movement is suggested by fracturing and by the uneven extinction of the grains. Minute crystals of zircon, rutile, sphene, and muscovite occur sporadically.

Hornfels Derived from Aluminous Sedimentary Rocks. The massive andalusite-bearing rock that lies at the top of the Chicopee Canyon formation is lacking in structure. That the rock was formerly an aluminous clay or mudstone is inferred from the abundance of andalusite, which composes from 10 to 50 percent of the hornfels.

The spongiform porphyroblasts of andalusite are as long as 3 mm. They enclose red-brown biotite, muscovite, and quartz, and lie in a granoblastic mosaic composed of the same minerals. Less abundant minerals include sericite, apatite, sphene, magnetite, hematite, and minor chlorite. In a section that contains about 50 percent andalusite, the mineral has been partly replaced by radiating intergrowths of muscovite and green biotite (fig. 8). Other specimens that contain less andalusite have greater amounts of muscovite. The increase in muscovite relative to andalusite seen in thin section is accompanied by a change in color of the associated biotite from red-brown to green, and by a decrease in specific gravity of the rock. The specific gravity ranges from 2.83 for specimens containing about 50 percent andalusite to 2.77 for those containing about 10 percent of the mineral.

Metamorphic Facies

The degree of metamorphism attained in the Chicopee Canyon formation may best be defined with reference to the mineralogical phase rule (Goldschmidt, 1911) and to the principle of metamorphic facies (Eskola, 1920; Turner, 1948). Critical mineral assemblages, indicative of medium-grade metamorphism according to the facies concept, are: (1) muscovite-biotite-andalusite-quartz-pelitic hornfels; (2) sphene-diopside-hornblende-albite-epidote calc-silicate hornfels; and (3) muscovite-biotite-oligoclase-microcline-quartz psammitic hornfels.

The examples described fairly represent the stratigraphic sequence. Hornfels (2) was collected about 420 feet stratigraphically below (1). Hornfels (3) is approximately 1100 feet below (2). Differences in the chemical composition of the rocks are indicated by their mineralogy but all may be tentatively assigned to the amphibolite facies or the epidote-amphibolite facies. The association of albite-epidote-hornblende in assemblage (2) is critical for the epidote-amphibolite facies, whereas the presence of oligoclase (rather than albite) in assemblage (3) places that hornfels in the higher grade amphibolite facies (Turner, p. 78, 84, 90). The association andalusite-muscovite is critical for the amphibolite facies (Turner, p. 77); however, the muscovite of hornfels (1) is at least in part a product of retrogressive metamorphism.

Retrograde Changes. Post-crystallization faulting in the Chicopee Canyon formation probably accounts for the evidence of strain seen in xenoblastic quartz.

The general absence of chlorite from the common association of biotite and muscovite shows that no widespread retrogressive changes have taken place in the lower member of the Chicopee Canyon formation. The partial replacement of diopside pyroxene by hornblende in the calc-silicate hornfels probably represents a mineralogical adjustment to falling temperature, and the granoblastic texture of the pelitic hornfels at the top of the formation has been modified by retrogressive changes. The common partial replacement of andalusite by muscovite suggests that potash was locally introduced, probably during intrusion of biotite quartz monzonite. The alumina set free by metasomatism of andalusite could have gone into the formation of green biotite. In the lower part of the formation sericitized

microcline is commonly interstitial to quartz. There is no evidence that the tonalite porphyry which intrudes the lower part of the section contributed material to the formation of new minerals during metamorphism. The rare tourmaline is probably of detrital origin.

Furnace Formation of Carboniferous Age

Name and Distribution

The name Furnace limestone was given by Vaughan to a thick section of carbonate rocks exposed in Furnace Canyon. On his map the formation is shown to underlie 40 square miles in scattered areas west, south, and east of the type locality. About a third of the total area of outcrop mapped by Vaughan is exposed in the area studied. Additional carbonate deposits underlie parts of the adjacent unmapped Deep Creek quadrangle.

Variability in texture, composition, and degree of metamorphism in the predominantly carbonate rocks makes designation by a single rock name misleading, as has been shown by later work east of the area mapped for this report. For this reason the name Furnace formation is used in this paper. Woodford and Harriss retained the name Furnace limestone but reported the presence of dolomite and the common occurrence of tremolite and other metamorphic minerals in the crystalline limestones of the Blackhawk Canyon area. Guillou also retained Furnace limestone as a formation name; he described the carbonates as marbles and partly subdivided them on the basis of color as gray, white, and black members.

Lithology and Internal Structure

In the area studied the Furnace formation consists chiefly of marble roof pendants and xenoliths intruded and isolated by plutonic rocks. There are no persistent stratigraphic guides. Partial or complete replacement of limestone by dolomite, followed by deformation and medium-grade metamorphism has, in many places, obscured color banding as well as original bedding features of the carbonate rocks. The term marble is used where the carbonates have developed a megascopic granoblastic texture as a result of any of these processes. Where not megascopically crystalline, the carbonates invariably show a microcrystalline texture.

Relics of detrital origin in the predominantly massive marbles are lenticular and commonly fine-grained. Thin lenses of chert, siltstone, and massive quartzite are the best local guides to structural trends; these are, however, rarely thick enough to be mapped and nowhere persistent enough to be used as markers for the separation of members. Minor lithologic units within the formation are delineated as lenses on the geologic map.

Exposures of the Furnace formation are present both south and north of the alluviated Holcomb Valley. The rocks first described in the following paragraph are considered to be the older.

Exposures South of Holcomb Valley. North of Bertha Peak and west of Poligue Canyon the Furnace formation overlies Chicopee Canyon quartzite. In its few exposures the contact appears to be conformable. The basal rocks commonly consist of massive dolomitic marble, ranging from 50 to 150 feet in thickness. Locally the

marble is thin-bedded. One mile northeast of Fawnskin a recemented limestone breccia is exposed near the base of the formation. The rotated clasts in the breccia, as much as 6 inches in diameter, have better preserved bedding features than were seen in any of the overlying rock. Except for rare lenticular siltstones near the base, the Furnace formation south of Holcomb Valley is made up altogether of carbonates.

A characteristic local feature of the formation is the rather common occurrence of thinly laminated dark aluminous layers interbedded with lighter-colored limestone. Scattered rounded fragments of medium- to fine-grained quartz are preserved in these laminated carbonates as rare relics of elastic origin.



Figure 9. Massive calcite and dolomitic marble of the Furnace formation north of Holcomb Valley. West side of lower Furnace Canyon.

Exposures North of Holcomb Valley. The oldest rocks of the Furnace formation north of Holcomb Valley are exposed in the lower walls of upper Crystal and Furnace Canyons. They consist of massive calcite and dolomitic marbles with subordinate amounts of limestone and dolomite. Original structures are rarely preserved (fig. 9). The marbles grade upward in the canyon walls to dolomitic limestone that shows relic bedding. Bedding is usually marked by lenticular siliceous layers a few millimeters thick that separate much thicker layers of carbonates. In a few places bedding is shown by thin lenses of detrital quartz.

Finely laminated argillaceous limestone exposed above the east fork of upper Furnace Canyon resembles laminated limestones in the Bertha Peak area and offers the only distinct lithologic correlation with the carbonates south of Holcomb Valley. In Furnace Canyon, however, the laminated limestones are only a few feet thick and they are underlain by perhaps 1000 feet of massive white marble that is not present south of Holcomb Valley.

Figure 10. Furnace formation. Dolomitic marble and dolomite, north of Holcomb Valley. East side of lower Furnace Canyon. Dolomitic marble grades upward to dolomite.



Figure 11. Coninio-type corals in the Furnace formation at locality 5. Elevation 7627 feet.

At higher elevations west of Furnace Canyon, the Furnace formation grades upward to massive calcite and dolomite marble. Evidence that the carbonate rocks are in part of bioclastic origin may be seen along the eastward-trending road in the $S\frac{1}{2}$ sec. 24, T. 3 N., R. 1 W., where fragmental crinoid stems are abundant in a lens of recrystallized limestone that may be 200 feet thick.

Tongues of Micaceous Siltstone and Massive Quartzite. Additional evidence of the partly detrital character of the Furnace formation is furnished by tongues of fine-grained micaceous siltstone and massive quartzite mapped in the roof pendant area near the boundary of secs. 25 and 26, T. 3 N., R. 1 W. The quartzite shows no bedding planes, but the underlying limestone and the overlying micaceous siltstone dip northwest (fig. 17). Slightly differing structural trends suggest that the

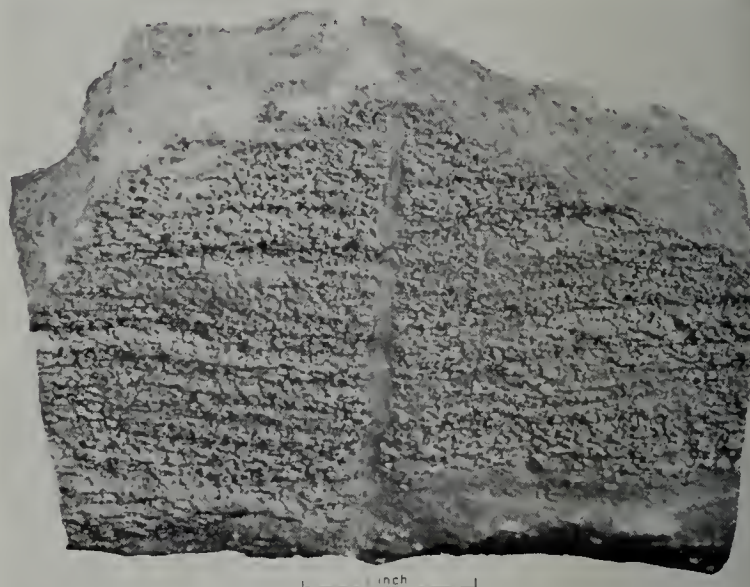


Figure 12. Detail of hand specimen of dolomitized limestone, Furnace formation.

clastic lenses may represent a local unconformity in the Furnace formation. An apparently conformable lens of quartzite was mapped for a short distance eastward from Greenlead Camp ($N\frac{1}{2}$ sec. 27, T. 3 N., R. 1 W.).

Dolomite Lens. On the east side of Furnace Canyon dolomite marble grades upward to dolomite (fig. 10). Although excellent bedding structures are well preserved in some places, the dolomite lacks stratigraphic continuity for designation as a member and it is delineated on the geologic map as a lens in the Furnace formation. In comparison with corresponding properties in the undifferentiated formation, the dolomite lens is characterized by the relative abundance of cherty layers and sandy streaks, by finer grain size, a better degree of bedding, and by a somewhat more consistent darker gray color.

Lenses of black aphanitic bedded chert, as thick as 3 feet in a few places and traceable for distances up to 200 feet, are local diagnostic features of the dolomite lens. Most of the chert layers are only an inch or two thick, however. They are well exposed on the ridge between Arctic and Furnace Canyons and in Wild Rose Canyon.

Thickness

South of Holcomb Creek the minimum thickness of the Furnace formation is probably 1000 feet, as judged by reconnaissance to the east of Bertha Peak. In the mapped area west of Bertha Peak, however, the section is so dissected by intrusive rocks that there is no continuous exposure of such thickness. North of Hol-

given later for considering much of it to be of replacement origin. The thickness of the formation suggests remarkably uniform conditions in a marine environment for a long period of time.

Age and Correlation

Poorly preserved fossils were collected from the Furnace formation north of Holcomb Creek at 17 localities shown on the geologic map. Fossils from locality 3 have been reported previously by Woodford and Harriss as of probable Mississippian age. Some of the other fossiliferous localities are represented by single specimens. In order of abundance the collections include corals, brachiopods, and bryozoans. Crinoid columns are locally abundant but were not carefully collected.

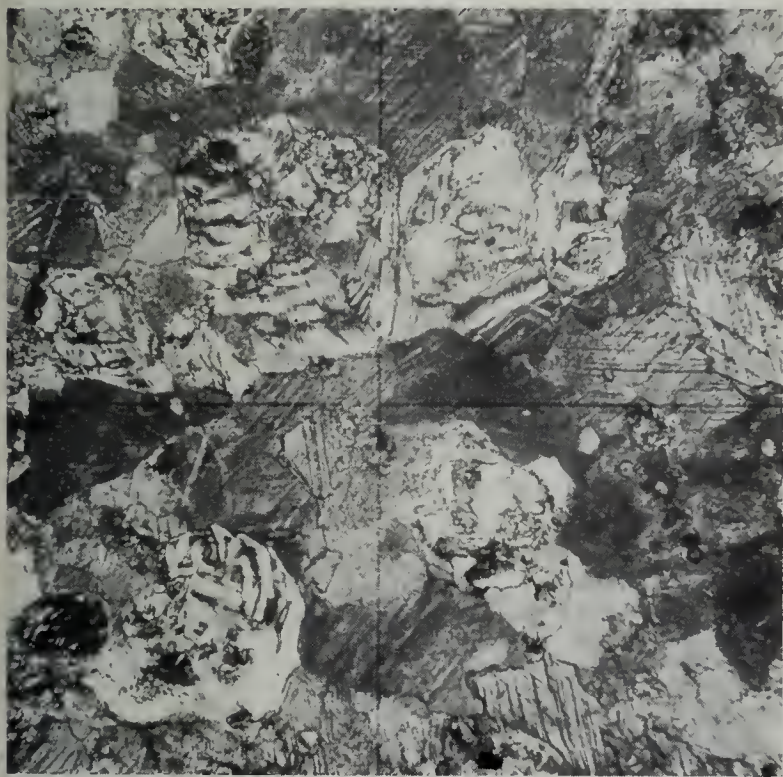


Figure 13. Photomicrograph. Brucite (white) in dedolomitized magnesian limestone, Furnace formation. Crossed nicols, x 25.

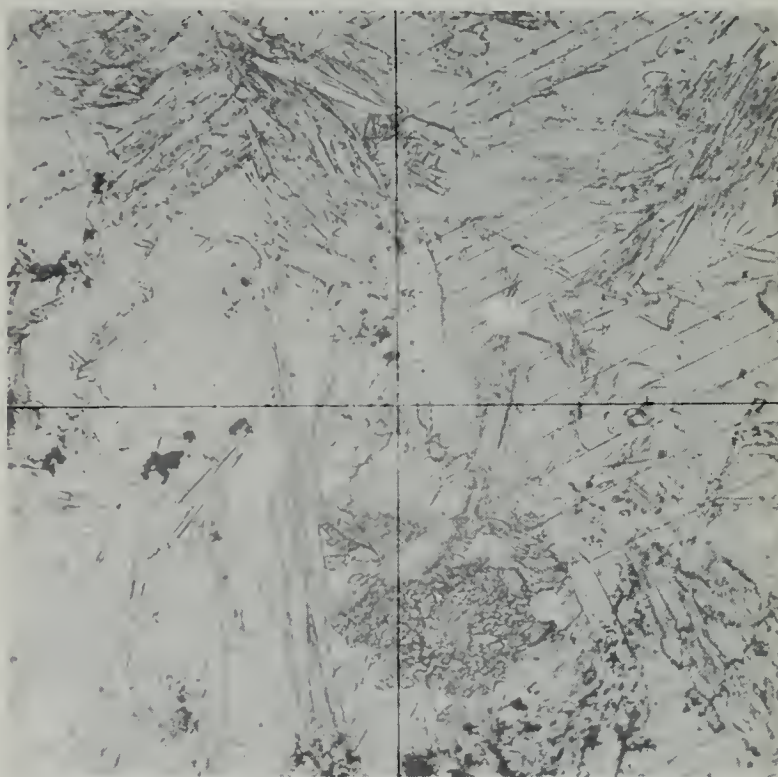


Figure 14. Photomicrograph. Granoblastic tremolite in dolomite. Furnace formation. Ordinary light, x 21.

comb Creek along the range scarp the Furnace formation may have a thickness of 4000 feet if the section is not repeated by isoclinal folding. The rarity of well-preserved bedding made it impractical to measure sections.

Conditions of Sedimentation

Post-depositional alteration masks most of the features bearing on the original character of the Furnace formation. Rare relics of detrital quartz and sporadic tongues of siltstone and quartzite show that the Furnace formation was in part of clastic origin. Fragmental crinoid stems in other places suggest a partly bioclastic origin. Dolomite widely distributed through the carbonate rocks may in part be of primary origin, but evidence will be

The stratigraphic position of localities 11-15 is not certainly known with respect to other localities. Beds of localities 11-14 are probably several hundred feet above the base of the formation but may underlie beds of localities 1-10 and 15-17. Most of the fossiliferous localities lie in the 2-mile strip of roof pendants that trends northwestward from Holcomb Valley. Topographic and structural evidence there indicates that the fossils do not represent a single stratigraphic horizon. Displacement may have occurred along some of the dikes that cut the formation; but the localities probably still represent more than 1000 feet of section (see structure section B-B', pl. 2).

The fossils were examined by Dr. Charles W. Merriam of the U. S. Geological Survey, who described them as follows:

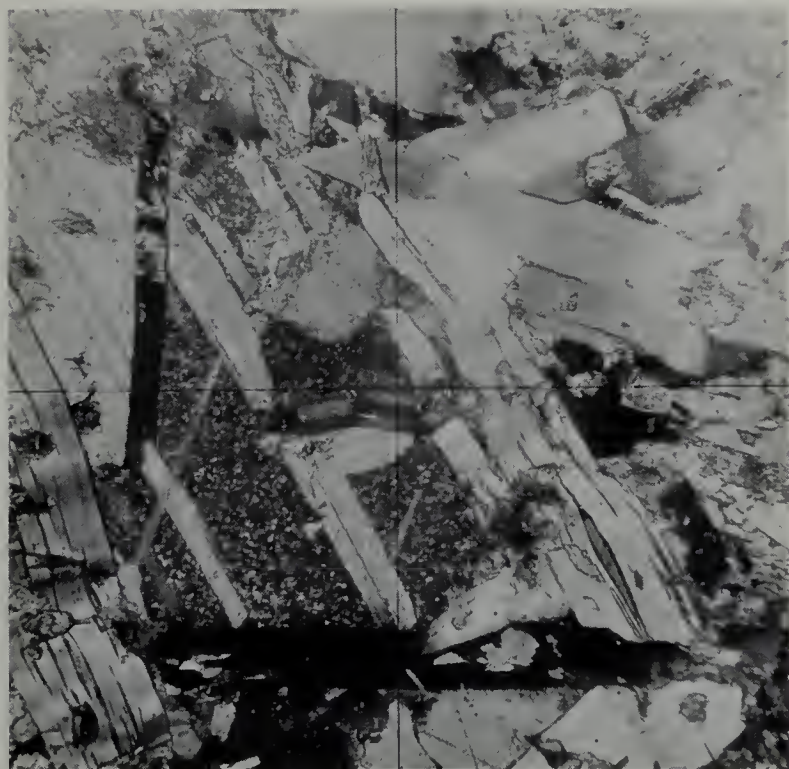


Figure 15. Photomicrograph. White chlorite (straight extinction) in quartz-calcite-tremolite-diopside-hornfels, Furnace formation. Crossed nicols, x 24.

Furnace Limestone Fossils

Caninia n. sp. (large form, abundant?)

Eumetria sp., cf. *E. altirostris* White

Dictyoclostus sp.

Spirifer cf. *centronatus*

The fossils listed appear to confirm a Lower Carboniferous, probably a Mississippian age. *Spirifers* of the *centronatus* type suggest relationship to the Rocky Mountain and Great Basin lower Mississippian (Madison) interval. Large solitary corals of the *Caninia* group, while ranging widely through the Carboniferous, are quite common and locally very characteristic of limestone facies in the North American Mississippian. *Eumetria* is perhaps the strongest evidence for a Mississippian assignment of the Furnace limestone. The brachiopod genus in question is known to be common in Mississippian strata; that it ranges higher is not yet known with certainty.

The Furnace fossils suggest that this formation is older than the conglomeratic limestones at Victorville which are believed to be Upper Carboniferous or Permian.

In terms of the southern Great Basin and Death Valley sections the Furnace fauna suggests a zone somewhere within the interval between the base of the Tin Mountain or Joana limestone (Madison) and the top of the White Pine Group, which last horizon is either high Mississippian or early Pennsylvanian.

Of the identified forms, *Caninia* corals are most abundant at locality 5 (fig. 11). The *Eumetria* species is from locality 13 (elevation 5600 feet), *Dictyoclostus* from locality 8, and *Spirifer centronatus* from locality 16.

Nearly 2000 feet of carbonate rocks may overlie the highest reported fossil occurrence if locality 15, which contains worn unidentifiable shell fragments that appear to have been reworked, is disregarded. Weathered surfaces of some of the overlying rocks show gross outlines of structures that may be fusulinid tests. Similar structures were seen in exposures near localities 1, 2, and 8. Metamorphism has destroyed beyond recognition the structural details of these relics. The facts suggest the possibility that the upper part of the undifferentiated Furnace formation is of Pennsylvanian age.

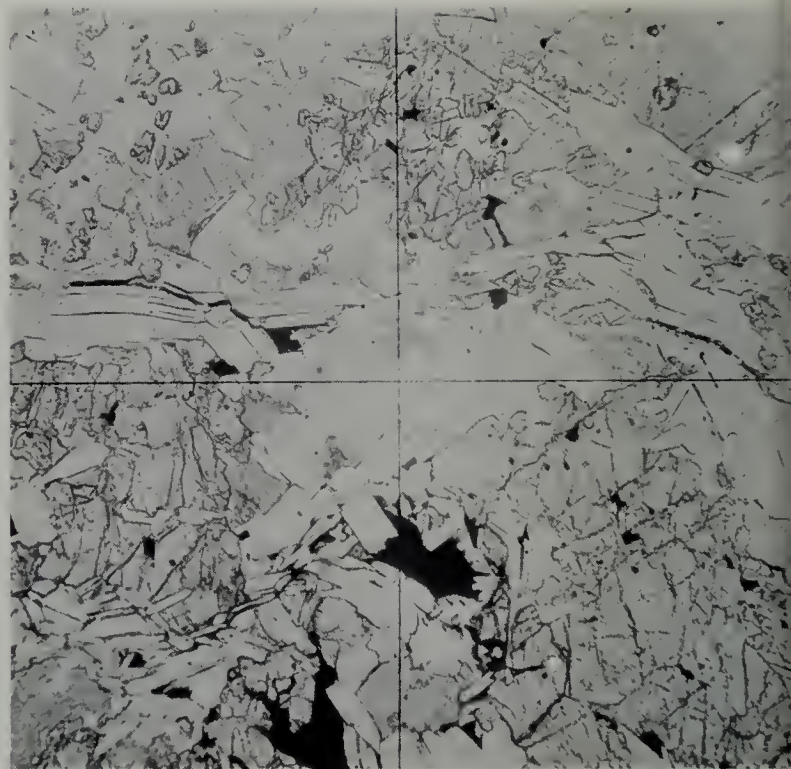


Figure 16. Photomicrograph. Chlorite replacement of dolomite and forsterite, Furnace formation. Ordinary light, x 14.

Structural Relations and Age of Deformation

South of Holcomb Valley the Furnace formation overlies the Chicopee Canyon formation with no direct evidence of unconformity. Both formations have there been intruded by tonalite porphyry and hornblende quartz monzonite.

Structural trends north of Holcomb Valley and the absence of a lower contact with the Chicopee Canyon formation indicate that the beds in that area are stratigraphically above those to the south, but the precise relations are not known.

North of Holcomb Valley the Furnace formation has been isolated in roof pendants by igneous intrusions. Only tentative correlations can be made between larger roof pendants northwest of Holcomb Valley (pl. 1, secs. 23, 24, 25, and 26, T. 3 N., R. 1 W.). In the vicinity of Greenlead Camp (N $\frac{1}{2}$ sec. 27, T. 3 N., R. 1 W.) small tight folds plunge in a westerly direction. Farther east the large roof pendant in sec. 23 has the form of a northwest-plunging syncline. The southern extension of the synclinal axis has not certainly been located, but mapped attitudes suggest a southeasterly trend toward Holcomb Valley. Siltstone and massive quartzite lenses that slightly modify this trend (NW $\frac{1}{4}$ sec. 25, T. 3 N., R. 1 W.) may represent local unconformities in the formation. The evidence for pre-batholithic deformation rests principally on the northwesterly trend of dikes that cut the Furnace formation without regard to local structures in the marble. Some dikes cut across minor folds; others are seen with steep dips nearly parallel to screens of marble. Some of the dikes are of pre-batholithic age.

Anomalous attitudes in the structure of many other roof pendants are thought to be explained by differential movement that occurred during the regional invasion by the batholith.

Post-batholithic deformation is shown by faulting which has thrust the Furnace formation over the biotite quartz monzonite east of Furnace Canyon; it will be described with the late Cenozoic structures of the area.

Pre-Batholithic Alteration

Dolomitization and local silicification evidently preceded the intrusion of the batholith because rocks affected by these changes later experienced igneous metamorphism.

Dolomitization. Field and laboratory tests confirm the abundant presence of dolomite in the Furnace formation of the mapped area. Cold dilute hydrochloric acid proved to be the most reliable qualitative field aid to the identification of dolomite. Megascopic tremolite commonly found indicates magnesian content in some of the limestones. Where dolomite and calcite grains are both present, the uneven weathering surface formed by the more resistant dolomite is another useful field guide to partly dolomitized rocks (fig. 12).

Several types of laboratory tests corroborate the presence of dolomite in the Furnace formation. The California State Division of Mines arranged to have chemical analyses made of 20 samples of the least altered carbonate rocks. These analyses show a considerable range in composition (table 1). About 75 additional samples were stained with copper nitrate according to the technique reported by Rodgers (1940). Tests of specific gravity were made of specimens where other techniques indicated a high degree of purity for either calcite or dolomite. In the study of 65 thin sections from the Furnace formation, the common occurrence of such magnesian minerals

as tremolite, forsterite, diopside, brucite, and serpentine indicates the presence of dolomite prior to metamorphism.

The age of the dolomitization is of geologic interest. In some field exposures dolomite marbles grade laterally and vertically into marbles composed principally of calcite. The checkerboard nature of these exposures is the chief reason for considering the dolomite to be of replacement rather than of primary origin. In the west wall of Furnace Canyon above the forks, a nearly horizontal bed of dolomite marble 50 feet thick, when traced laterally for a short distance, is transitional to patchy dolomitic and calcite marble. The lack of marker beds and the effects of later deformation and metamorphism limit the number of observations that suggest the manner in which dolomitization occurred on a large scale.

On a smaller scale there are minor indications that dolomite selectively formed along stratigraphic layers (fig. 12). Stain tests of hand specimens show that individual grains of dolomite in the partly dolomitized carbonates are as much as 2 mm in diameter; some are idiomorphic crystals, but coarse anhedral grains are more common. These are either scattered or clustered in layers that mark bedding planes in the finer-grained massive calcite.

The slightly metamorphosed dolomite lens mapped in the Furnace formation has a comparatively uniform stratigraphic character verified by the localization of cherty and sandy layers in intermittently traceable horizons and by a greater consistency of color banding.



Figure 17. Micaceous siltstone lens, Furnace formation, in NW corner sec. 25, T. 3 N., R. 1 W. Elevation 7450 feet.



Figure 18. Hematite skarn, Furnace formation, at Desert View mine, NE 1/4 sec. 27, T. 3 N., R. 1 W. Elevation 7500 feet.

Table 1. Chemical analyses of carbonate rocks from the Furnace formation.

Analyst—Abbot A. Hanks, Inc., San Francisco, Calif. (1954)

No.	CaO %	MgO %	SiO ₂ %	Fe ₂ O ₃ %	Al ₂ O ₃ %	P ₂ O ₅ %	Location of sample	Elev. in ft.
1b.....	30.86	21.16	0.20	0.35	0.46	0.08	1600'E, 200'S of NW cor. sec. 24, T 3 N, R 1 W.	7350
2b.....	52.41	1.14	3.64	0.08	0.22	0.01	2300'E, 800'N of SW cor. sec. 23, T 3 N, R 1 W.	7600
3b.....	54.63	0.41	0.98	0.08	0.06	0.01	2600'N, 200'W of SE cor. sec. 23, T 3 N, R 1 W.	7900
4b.....	53.67	0.81	1.88	0.14	0.12	0.01	2500'E, 2500'N of SW cor. sec. 23, T 3 N, R 1 W.	7900
5b.....	29.95	13.69	14.64	0.43	2.09	0.01	1750'N, 2500'W of SE cor. sec. 13, T 3 N, R 1 W.	6550
6b.....	46.79	4.80	4.72	0.57	1.05	0.03	1700'N, 1300'W of SE cor. sec. 12, T 3 N, R 1 W.	4800
7b.....	30.08	21.28	0.76	0.24	0.24	0.01	2200'W, 2050'S of NE cor. sec. 19, T 3 N, R 1 E.	6650
8b.....	48.87	5.23	0.80	0.21	0.25	0.01	450'E, 1000'S of NW cor. sec. 19, T 3 N, R 1 E.	5900
9b.....	50.30	3.55	1.62	0.18	0.48	0.02	1500'E, 1450'N of SW cor. sec. 18, T 3 N, R 1 E.	5350
10b.....	38.56	5.71	26.24	2.12	2.76	0.27	850'E, 100'N of SW cor. sec. 25, T 3 N, R 1 W.	7275
11b.....	29.70	21.03	2.02	0.30	0.40	0.01	300'S, 1650'E of NW cor. sec. 20, T 3 N, R 1 E.	7100
12b.....	29.94	21.58	0.58	0.21	0.23	0.01	1100'N, 1350'W of SE cor. sec. 17, T 3 N, R 1 E.	5800
13b.....	54.63	0.28	0.30	0.08	0.78	Trace	100'E, 1750'S of NW cor. sec. 16, T 3 N, R 1 E.	5300
14b.....	29.82	21.15	2.34	0.15	0.19	0.03	Extreme SE cor. sec. 19, T 3 N, R 1 E.	7850
15b.....	30.79	21.12	0.28	0.17	0.13	0.01	200'E, 2500'S of NW cor. sec. 20, T 3 N, R 1 E.	7925
16b.....	31.31	20.59	0.48	0.15	0.19	0.02	1100'E, 1950'S of NW cor. sec. 30, T 3 N, R 1 E.	7500
17b.....	52.35	2.46	0.92	0.23	0.41	0.01	2350'E, 2350'S of NW cor. sec. 24, T 3 N, R 1 W.	7500
18b.....	52.03	2.27	1.72	0.09	0.41	0.01	1200'W, 1100'N of SE cor. sec. 24, T 3 N, R 1 W.	7300
19b.....	52.88	1.93	1.10	0.11	0.03	Trace	450'E, 1350'S of NW cor. sec. 8, T 2 N, R 1 E.	7275
20b.....	54.88	0.67	0.20	0.05	0.25	Trace	650'W, 800'S of NE cor. sec. 36, T 3 N, R 1 W.	7200

The least altered rocks indicate that dolomitization was not accompanied by notable change in color. Fine-grained dolomite which locally grades to fine-grained gray limestone in the dolomite lens at an altitude of about 7750 feet (NW $\frac{1}{4}$ sec. 30, T. 3 N., R. 1 W.), is only slightly darker in color. Stain tests and a specific gravity of 2.84 confirm field and microscopic evidence that the dolomite is nearly pure. Scattered small blades of tremolite are present, however, which proves that the least altered rocks have undergone some metamorphism.

Silicification. Silica in the Furnace formation has two principal modes of occurrence. Bedded cherts and siliceous layers are considered to be of primary origin because they lie parallel to bedding planes that are locally confirmed by relics of clastic origin. Putty-white to dark-brown nodular cherts have a different mode of occurrence, and field evidence indicates that they were formed by replacement of earlier materials. The nodular cherts have colloform shapes that range from almost spherical through various kinds of tuberous forms. Most of the forms are aligned roughly parallel to the bedding; but the growth of some of them across bedding planes proves their secondary origin. The length of the nodules ranges from 1 to 10 inches. Cross sections show that the larger nodular masses are not all solid. A thin shell of nodular chert in massive marble may be seen in cross section to enclose other carbonates or metamorphic minerals. Some of the smaller chert shells partly enclose large bladed tremolite crystals that radiate inward toward a common center like spokes in a wheel. This relationship proves that dolomitization has preceded the silicification.

There is no apparent spatial relation between the nodular cherts and granitic rocks, but the nodular cherts are commonly concentrated in irregular colloform masses in the immediate vicinity of poorly preserved fossils. Where chert pseudomorphs of gross organic shapes are most abundant, silicified relics of organic structures are most likely to be found. Many of them can be recognized as brachiopods, crinoid columns, corals, and bryozoans.

This association is considered to show that some of the nodular cherts incompletely replaced the fossil forms of primary calcareous organisms. No relics of primary siliceous or aragonitic organisms were found.

Contact Metamorphism

The general absence of foliated rocks in the Furnace formation suggests that strong shearing stresses were not in operation during intrusion of the batholith. Direct evidence to support this conclusion is rarely preserved because of the widespread recrystallization of the carbonates. Fragmental unoriented crinoid columns seen in several localities show only moderate flattening parallel to the bedding planes. Tongues of siltstone and quartzite are not sheared. Metamorphic minerals developed in contact zones have a typical decussate structure that suggests static metamorphism.

Two types of alteration in the Furnace formation are considered to be directly related to igneous intrusion. The effects of normal contact metamorphism that will be first discussed include marmarization, dedolomitization, and the formation of new minerals in hornfelses of low and medium metamorphic rank with no apparent introduction of additional materials into the host rock.

The second type of igneous metamorphism is prevalent at many contacts in the area. At short distances from granitic contacts iron, sulfur (as sulfide), probably silica and aluminum, and locally tungsten were added to the host rock to form skarns and tactites.

Marmarization. The most noticeable megascopic effect of contact metamorphism in the carbonate rocks of the Furnace formation is an increase in grain size accompanied by bleaching to a lighter color. The field term marmarization has been used to describe these initial changes in the recrystallization of limestone to marble. Near intrusive contacts the individual crystals are coarse and the rock is light in color compared with the same properties at a distance from such contacts. These changes in color and grain size cut across local contacts between calcite and dolomite marbles. This is the prin-

incipal evidence for considering much of the light color of the marbles to be a secondary effect of marmorization, and for discarding color banding as a possible basis for subdivision of the formation. The evidence also supports the conclusion that dolomitization preceded metamorphism and indicates that magnesia was not introduced by the batholith on a regional scale.

Dolomitization. Additional evidence that dolomitization preceded metamorphism is the evidence that dolomite, as a result of metamorphism, partly lost its content of magnesium carbonate although magnesium was retained in the rock as a hydroxide or silicate. A thin section of a specimen collected 50 feet above the visible contact with biotite quartz monzonite in Furnace Canyon opposite the mouth of Wild Rose Canyon, shows a granoblastic mosaic of brucite, forsterite, calcite, and a few grains of hematite. Brucite is isolated in tiny pods of finely crystalline aggregates that contain partly replaced patches of forsterite (fig. 13). The presence of brucite was confirmed by tests of specific gravity in Clerici solution and by matching the reflective index N_o in oils. The specific gravity of the brucite is 2.53; the index $N_o = 1.568$.

Petrography of the Hornfelses

Nearly all the rocks of the Furnace formation have experienced at least a low grade of metamorphism, becoming progressively more intense toward igneous contacts. The rarity of pelitic sediments and stratigraphic guides, the variety and complexity of the igneous intrusives, and the generally poor exposures of igneous contacts made it impractical to map metamorphic zones. In the petrographic descriptions that follow, the rocks are first classified on the basis of composition at the time of metamorphism without regard to stratigraphic position. The general mineralogy of each group is then given with descriptions of representative hornfelses. Thin sections selected for description were chosen with two purposes: (1) to best demonstrate the general metamorphic grade attained by rocks of different composition with relation to igneous contacts, and (2) to show the thermal effects of the different kinds of intrusive bodies.

Hornfelses Derived from Dolomite and Magnesian Limestones. Rarely dolomite is recrystallized to a fine-grained granoblastic aggregate in which metamorphic minerals are not seen. More commonly the dolomitic rocks contain tremolite, forsterite, and diopside. Quartz is relatively rare; when present, it is seen to occur with muscovite, epidote, and clinozoisite, or tremolite. In thin sections that contain quartz and tremolite, needles of tremolite lie across quartz boundaries and in a few thin sections form inclusions in the quartz.

Tremolite is the most widely developed metamorphic mineral. It occurs at considerable distances from visible igneous contacts; the isolation of the carbonate rocks in roof pendants, however, indicates that the intrusive rocks may be within short distances of the surface. In a thin section of a specimen taken from the roof pendant on the ridge south of Wild Rose Canyon, about half a mile from a contact with biotite quartz monzonite, unoriented blades and sheaves of tremolite lie in a mosaic that includes both calcite and dolomite, an assemblage critical for low-grade metamorphism (fig. 14).

Diopside and forsterite were found to occur only within distances less than 50 feet from igneous contacts. Tremolite was not seen to occur with forsterite and is associated with diopside in only two thin sections. One of these, from a specimen collected 6 inches from a contact with tonalite porphyry on the west side of Bertha Peak, is of interest for the abundance of an unusual white chlorite of very low birefringence. The chlorite forms a part of the granoblastic mosaic of diopside, tremolite, and calcite, in which a small amount of quartz is the only other mineral. The interpenetrating laths of the chlorite are commonly somewhat bent (fig. 15). They have negative elongation, straight extinction, and a positive uniaxial sign. In oils the refractive indices of cleavage fragments are $N_o = 1.582$ and $N_e = 1.584$. The mineral may be leuchtenbergite.

Forsterite occurs with another chlorite in a chlorite-forsterite-dolomite hornfels collected about 100 feet from a contact with biotite quartz monzonite opposite the mouth of Wild Rose Canyon. Porphyroblasts of forsterite as much as 2 mm in diameter enclose dolomite. A few grains of pyrite are present. The chlorite forms oriented laths that partly replace dolomite and forsterite (fig. 16). Both forsterite and chlorite are locally replaced by serpentine. The relation suggests that the rock was chloritized after it was metamorphosed but before it was serpentinized. The chlorite has negative elongation, straight extinction, and a positive $2V$ of 4° estimated from the biaxial interference figure. In oils, the refractive indices are $N_x = 1.630$ and $N_y = 1.635$. The properties are close to those of ripidolite.

Magnesian marble collected 12 inches from a contact with hornblende quartz monzonite in the canyon east of Poligue Canyon, shows forsterite centers in pools of fibrous serpentine which are in turn set in a granoblastic calcite matrix. This mineral association has long been known to result from the thermal metamorphism of impure magnesian limestones (Harker, 1904).

Hornfelses Derived from Non-magnesian Limestones. Sections of the calcite limestones and marble occasionally contain only granoblastic calcite. At a distance of 500 feet from a contact with biotite quartz monzonite, one section contains a few small grains of quartz and chlorite as the only impurity. In two specimens taken a foot from contacts with biotite quartz monzonite east of Arctic Canyon, the limestones have been reconstituted to coarsely crystalline wollastonite-calcite hornfelses.

Hornfelses Derived from Micaceous Siltstones and Argillaceous Sediments. Aluminous sediments rarely occur in the Furnace formation and were not seen at granitic contacts. They are most commonly associated with quartz in irregular lenses interbedded with either limestone or dolomite or their marbles.

A lens of micaceous siltstone that locally overlies quartzite and reaches an unusual thickness of 200 feet is exposed intermittently for half a mile in the roof pendant area northwest of Holcomb Creek (fig. 17). The siltstone is intruded by minor dikes of volcanic rock and granite porphyry. Low-grade biotite-quartz-muscovite hornfelses have been formed. They contain fine-grained granular quartz scattered evenly in a groundmass of scaly muscovite. The elastic origin of both minerals is shown by the rounded shape of the quartz grains and by the molding of the muscovite flakes around them. Neither

mineral is poikilitic, as would be expected if they were recrystallized. Brown biotite, isolated in small clumps, appears to be newly formed from muscovite. Rare crystalloblastic tourmaline probably represents a recrystallization of original detrital grains.

The micaceous siltstone grades upward in the field through 50 feet of rhythmically thin-bedded siltstone and limestone to massive gray calcite marble. The transitional beds contain a very fine-grained hornfelsed assemblage of actinolitic tremolite, clinozoisite, and calcite. The amphibole has an extinction angle of 20° , and is faintly pleochroic with $z' =$ light-gray green.

The laminated argillaceous limestone south of Holcomb Valley, 200 feet from the contact with tonalite porphyry, shows millimeter-thick bands of very fine-grained clinozoisite interlayered with thicker bands of coarse calcite. A few rounded grains of quartz are scattered through both layers.

In the Furnace formation north of Holcomb Valley the rare aluminous layers usually occur as thin lenses commonly traceable for less than 20 feet. One specimen was collected from a pelitic layer 3 feet thick contained in a small limestone roof pendant isolated by biotite quartz monzonite west of Crystal Creek. The igneous contact is 75 feet distant. In thin section fine-grained poikilitic quartz, biotite, muscovite, sericite, and andalusite are seen. The andalusite has been affected by retrograde changes, being replaced by scaly masses of sericite that have also attacked the edges of the olive-brown biotite.



Figure 19. Detail of skarn (dark area) in figure 18 suggesting replacement of marble.

Additive Contact Metamorphism

The name *tactite* was originally proposed by Hess (1919, p. 377-378) to designate rocks of complex mineralogy developed by the contact-metasomatic alteration of limestones and dolomites. The term is commonly used for soluble rocks into which foreign matter—particularly the metals gold, silver, lead, copper, zinc, tungsten, and molybdenum—has been introduced by hot solutions or gases from an intruding magma. The older term *skarn* is generally applied to silicate complexes associated with iron ores of contact-metasomatic origin.

Skarns and tactites are developed in lenticular masses parallel to contacts where the hornblende quartz monzonite and the biotite quartz monzonite have intruded the Furnace formation. They are usually only a few inches thick, but in a few places the host rock is sporadically affected as far as a hundred feet from igneous contacts.

It is difficult to distinguish between material that may have been reconstituted by normal contact metamorphism and that which may have been introduced by pneumatolysis or hydrothermal solutions. Materials of both modes of origin are intimately associated. The evidence that iron, sulfur (sulfide), probably silica and aluminum, and locally tungsten have been introduced into the skarns and tactites lies in the localized concentrations of these elements in minerals seen only at igneous contacts (fig. 18). The mode of occurrence of the minerals, which have the appearance of replacing part of the substance of the marble, also suggests that they have been introduced (fig. 19). The zones are widest where joints or bedding planes in the host rock are parallel to igneous contacts.

The contact-metasomatic rocks are called skarns if hematite or pyrite was observed. Rarely the skarns consist only of ledges of massive specular hematite and coarse epidote as thick as 10 feet (fig. 18). Epidote is concentrated in the central part of these masses, but it is also irregularly veined through the margins. Where hematite is absent the introduction of iron, sulfide, and aluminum is suggested in some places by rusty-brown weathering surfaces formed by disseminated massive calcium-iron garnet, or by a yellowish stain in the marbles that can be traced to minute pyritohedrons and cubes of pyrite.

Where iron oxides and sulfides were not seen to occur, the contact deposits are designated as tactites. The principal minerals of the tactites, some of which are also typical of the skarns, are garnet, diopside, tremolite, and epidote. Less common minerals include wollastonite, idocrase, and scheelite. Some of the rocks called tactites are probably true hornfelses, but locally they contain tungsten in the form of scheelite. The presence of scheelite has been cited as *prima facie* evidence of an additive process (Kerr, 1946, p. 43).

Petrography of Calc-silicate Tactites and Skarns. The four calc-silicate rocks described below are representative of several specimens sectioned. A calcite-quartz-pyrite-garnet rock occurs in a skarn zone sporadically developed on the west side of Furnace Canyon at the contact with biotite quartz monzonite. In thin section porphyroblastic garnet, closely associated with pyrite, contains poikilitic calcite and quartz. Secondary calcite

and quartz fill cracks in the garnet. In oils the garnet has a refractive index of 1.812, which suggests that it is a grossularitic andradite.

A sphene-clinozoisite-diopside-garnet rock was collected at the contact with hornblende quartz monzonite east of Delamar Mountain. The very fine-grained rock locally shows relic bedding in the megascopic rhythmic layering of reddish-brown and creamy-white colors at intervals of 1 cm. The red-brown layers are seen in thin section to consist of xenoblastic garnet that contains poikilitic diopside and clinozoisite. Epidote fills some cracks in the garnet that trend irregularly perpendicular to the layering. The light-colored layers are made up chiefly of clinozoisite that in some places encloses drop-like grains of sphene. In oils the garnet has an index of refraction of 1.768 which suggests that it is an andraditic grossularite.

A scheelite-tremolite-idocrase-garnet tactite was collected on the ridge east of Arctic Canyon 8 feet from the contact with a graphophytic variant of biotite quartz monzonite. In thin section a 2-cm porphyroblast of zoned bluish-gray garnet poikilitically encloses tremolite and calcite. The garnet shows anomalous birefringence. The poikilitic calcite in some places encloses small equant grains of scheelite, but scheelite, as well as idocrase, appears to be replacing garnet at the edge of the larger crystal. In oils the garnet has an index of refraction of 1.75, near grossularite. The presence in the tactite of about 1 percent of scheelite is confirmed by the ultra-violet lamp.

A granoblastic calcite-wollastonite-grossularite rock was collected from a tactite zone in the Furnace marble 18 inches from the contact with biotite quartz monzonite east of Greenlead Camp. Wollastonite occurs in radiating swirls throughout the thin section. Xenoblastic calcite contains small idiomorphic garnet crystals and is enclosed by garnet porphyroblasts in a way that suggests garnet was the last mineral to form. The garnet shows multiple zoning. Small cracks in the garnet, filled with veinlets of calcite, suggest some post-crystallization movement. The index of refraction of the garnet in oils is 1.755. The associated minerals and the refractive index indicate that the garnet has a composition near grossularite.

Metamorphic Facies

Of typical hornfelses that have been described the more critical ones are summarized below for consideration of the grade of static metamorphism attained in the Furnace formation.

- (1) Calcite-tremolite-dolomite hornfels about 800 yards from a contact with biotite quartz monzonite.
- (2) Andalusite-biotite-muscovite-quartz-sericite hornfels about 75 feet from a contact with biotite quartz monzonite.
- (3) Tremolite-diopside-calcite hornfels 6 inches from a contact with tonalite porphyry.
- (4) Calcite-wollastonite-grossularite hornfels (tactite?) 18 inches from a contact with biotite quartz monzonite.
- (5) Forsterite-calcite hornfels 12 inches from a contact with hornblende quartz monzonite.
- (6) Calcite-wollastonite hornfels at a contact with biotite quartz monzonite.
- (7) Diopside-clinozoisite-garnet calc-silicate rock at a contact with hornblende quartz monzonite.

The mineral assemblages show that the low grade of metamorphism reached at a distance from igneous con-

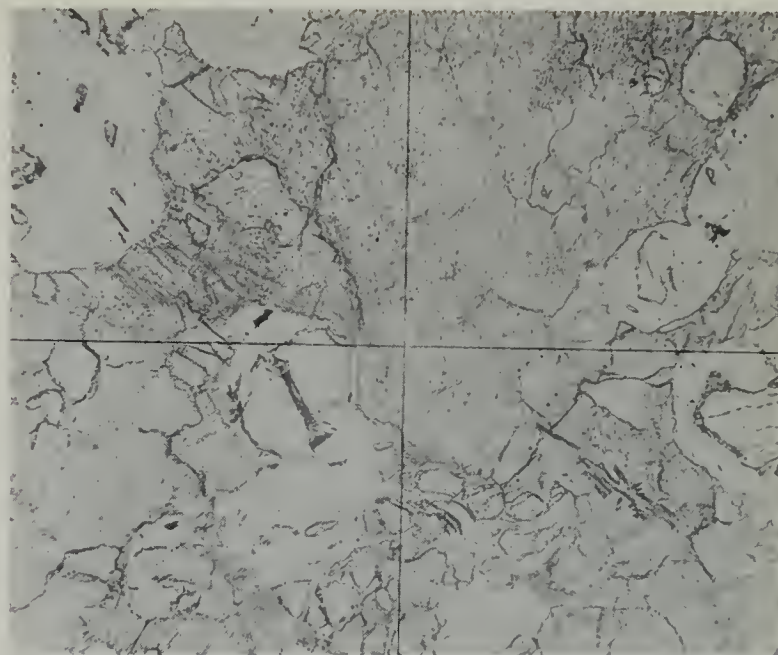


Figure 20. Photomicrograph. Pods of serpentine (white) replacing forsterite (right center, high relief) in calcite marble (dark gray), Furnace formation. Ordinary light, x 24.

tacts persisted nearly to the contacts, and that metamorphism was in general progressive toward contacts. The petrography of the hornfelses confirms a field observation that the degree of metamorphism was only slightly affected by the composition of the granitic intrusion. The more basic tonalite porphyry would be expected to exert a greater thermal effect because of its higher temperature of crystallization.

The difficulty in defining metamorphic facies in carbonate rocks has been discussed by Bowen (1940, p. 272-274). Changes in pressure due to the abundance of CO_2 contained in the system have an effect on the temperature range which determines the stability of a metamorphic assemblage. It is doubtful if any very high rank of metamorphism was attained in the Furnace formation. The contact aureole is very thin, and the typical metamorphic minerals (tremolite, forsterite, diopside, wollastonite, and garnet) are not characteristic of very high grade metamorphic assemblages. The calcite-tremolite-dolomite association is considered by Bowen (1940, p. 237-244) to represent the lowest step in the progressive metamorphism of silica-deficient dolomitic sediments. Tilley (1948, 1951), however, has since then described one step lower. Turner (1948, p. 92) correlates the calcite-tremolite-dolomite assemblage with the greenschist or epidote-amphibolite facies of Eskola.

Most of the contact rocks a few inches from the intrusive probably belong to the amphibolite facies defined by Eskola. Of the hornfelses listed on the preceding page, Nos. 2, 3, and 7 have been cited as typical of the amphibolite facies (Turner, p. 76-88). The equilibrium association of andalusite and muscovite is critical for the amphibolite facies. In the mapped area, however, sericite is surely retrogressive and muscovite is at least in part a product of retrogressive metamorphism at the expense of andalusite. The andalusite-biotite-muscovite hornfels may therefore have attained the higher grade pyroxene hornfels facies.

Retrograde Changes. The metamorphosed rocks of the Furnace formation have experienced minor changes that might be expected to be caused by the action of hydrothermal solutions during cooling of the batholith. The evidence consists of the partial replacement of minerals of higher metamorphic rank by those of lower grade. The changes are usually not apparent in a hand lens examination, but they have evidently occurred sporadically throughout the area.

A spongy cellular structure, accompanied by a distinctive yellow-brown color, is locally developed in recrystallized dolomite. Some sections of these rocks show only rather abundant irregular holes rimmed with a yellow stain. On the west side of Furnace Canyon (sec. 18, T. 3 N., R. 1 E.) and in the canyon east of Poligue Canyon (sec. 7, T. 2 N., R. 1 E.) the structures are traceable to small zones of partly serpentinized calcite marble. Relics of forsterite are seen in thin section to be preserved in the centers of the irregular pods of serpentine (fig. 20).

The partial replacement of grossularite by idocrase has been described as an early stage in the change from a higher to a lower degree of metamorphism (Harker, 1939, p. 347).

Other microscopic evidence of retrograde hydrothermal metamorphism is shown by the sericitization of andalusite and biotite in aluminous hornfelses, and by fillings of calcite and clinozoisite in fractured porphyroblasts of grossularite.

The Development of the Igneous Rocks

The record of igneous activity in the San Bernardino Mountains shows that volcanism, possibly of Triassic age, was followed in Jura-Cretaceous time by a phase of major plutonic and hypabyssal intrusion.

Metamorphosed volcanic rocks consist of quartz latite porphyry, quartz latite tuff, and trachyandesite. They are preserved partly in dikes and partly as migmatites with biotite quartz monzonite in scattered exposures that trend northwestward, in the direction of the adjacent Barstow quadrangle. Similar volcanic rocks that occur on Sidewinder Mountain in the Barstow quadrangle have a minimum thickness of 4000 feet (Bowen 1954, p. 43). This figure, added to the preserved thickness of the older sedimentary rocks, shows that the minimum thickness of cover may have been more than 10,000 feet in most of the area when the plutonic and hypabyssal rocks consolidated as part of a composite batholith.

The boundaries of the batholith, which underlies much of the San Bernardino Mountains and southeastern Mojave Desert, are not defined in this report. In the area studied, the exposed thickness of the batholith is 4000 feet. It is made up of small bodies of gabbro, diorite, and tonalite porphyry, and larger masses of hornblende quartz monzonite, biotite quartz monzonite, and granite porphyry.

The igneous rock units are discussed in order of probable decreasing age. Relative age relations are established for most types by means of intrusive relations with other rocks, or by petrologic comparisons with other rocks. Field relations show that the metavolcanic rocks are older than hornblende quartz monzonite, biotite quartz monzonite, and granite porphyry; however, the metavolcanic rocks are not in contact with gabbro, diorite, and tonalite

Figure 21. Screen of Furnace marble (white outcrop, right center) separating granite porphyry (right) from quartz latite porphyry (left). Head of Holcomb Creek.



Figure 22. Bonded quartz latite porphyry exposed in Coyote Canyon.

porphyry. Inasmuch as the plutonic rocks appear to be closely related in age, it is reasonable to assume that they are all younger than the volcanic rocks.

Diorite, hornblende quartz monzonite, and biotite quartz monzonite grade locally to a rock so altered by cataclasis that only rare relics of hypidiomorphic granular texture are preserved. The alteration is associated with thrust-faulting of late Cenozoic age. The rock unit is designated as granite cataclasite and described with the plutonic series.

The igneous rocks developed probably in the following sequence: (1) Injection and local eruption of volcanic rocks along northwest-trending fissures in folded sedimentary rocks. (2). Crystallization of gabbro and diorite. (3) Intrusion of tonalite porphyry in favorable wall rock structures. (4) Local forcible injection of hornblende quartz monzonite synchronous with additional deformation of wall rocks. Some continued differentiation by crystal settling. (5) Emplacement of biotite

Southeast of the exposures of migmatites, metavolcanic rocks form part of a complex of dikes and plugs that cut and isolate roof pendants of the Furnace formation (in secs. 36, 25, and 26, T. 3 N., R. 1 W.). There they consist of relics of quartz latite porphyry, quartz latite tuff, and trachyandesite. The metavolcanic rocks in places intrude the older sedimentary rocks, and both have been intruded by granite porphyry. Both kinds of intrusive rocks have been metamorphosed, so that groundmass textures are not readily distinguished with a hand lens. Because many of the igneous rocks in the roof-pendant area show under the microscope relics of porphyritic granular texture, they are mapped collectively as the porphyry complex. Volcanic associations in the porphyry complex are described here because of their local abundance and older geologic history. Granite porphyry is a later hypabyssal associate of the biotite quartz monzonite and its description will be postponed until the biotite quartz monzonite has been discussed.

General Character

Structure. Among the dikes that make up much of the porphyry complex, a northwesterly trend is demonstrable in a few areas of continuous exposures. The dikes consist of quartz latite porphyry that grades to quartz latite tuff, trachyandesite, and granite porphyry, and in general they dip 70° or 80° to the southwest. Granite porphyry as seen in areas of good exposures cuts all other dikes. Planar structures trend parallel to the dip in some of the quartz latite porphyry dikes (fig. 21). The trend of the dikes in some places follows, and in other places cuts across bedding in the older Furnace formation, indicating that the sedimentary rocks were deformed before the dikes were intruded.

Quartz Latite Porphyry. Banded and massive aspects of this rock can be distinguished. Banded rocks are intermittently exposed for a quarter of a mile along strike in the northwestward-trending canyon that heads in the NW cor. sec. 25, T. 3 N., R. 1 W. (fig. 22). The rocks strike N. 45° W., parallel to the axis of the canyon and generally dip 80° southwest. In order to simplify further reference to this canyon it is here referred to as Coyote Canyon.

Only the weathered surfaces of the banded rocks show structure; on fresh surfaces the rocks appear massive. Banding is shown by millimeter-thick laminations that apparently mark flow lines. Most of the banded rocks contain abundant phenocrysts of anhedral feldspar, ranging from 1 to 3 mm in length, which are disposed in subparallel lines. Some of the phenocrysts show evidence of rotation in a faint swirling of the flow lines. In a few outcrops color banding in light and dark shades of gray is parallel to the structural banding in the rock (fig. 23). Angular clasts of marble can be seen in some of the flow-banded quartz latite porphyry exposed in the floor of Coyote Canyon. These have long dimensions measuring from 1 or 2 mm to as much as 3 or 4 cm, and are aligned in trains parallel to the flow lines in the rock. The banded facies of quartz latite porphyry exposed in Coyote Canyon grades upward in the canyon walls into massive quartz latite porphyry.

The massive facies of quartz latite porphyry is characterized by anhedral white feldspar phenocrysts that range in size from 1 to 3 mm but rarely compose more

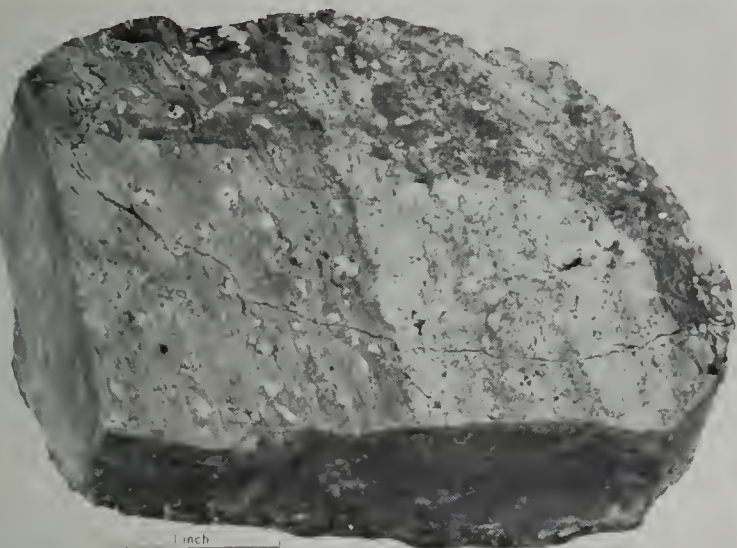


Figure 23. Hand specimen of quartz latite porphyry showing fluxion structure.

quartz monzonite on a regional scale, in part by stoping of wall rocks and in part by metasomatic replacement of volcanic rocks. (6) Final injection of granite porphyry as small plugs and dikes.

Volcanic Rocks and Their Relation to the Batholith

Distribution

Metamorphosed volcanic rocks, considered to be the oldest igneous rocks in the mapped area, are scattered in a narrow belt northwest of Holcomb Valley for a distance of 4 or 5 miles. They have two chief modes of occurrence.

In the northwest part of the belt, metavolcanic rocks were in part later migmatized by the action on them of the biotite quartz monzonite magma and its emanations. The most extensive areas of migmatites are shown on the geologic map.



Figure 24. Quartz latite porphyry intruded into Furnace morble, head of Holcomb Creek.

than 10 percent of the rock. Banding is absent. The aphanitic dark-gray groundmass is not easily distinguished from the fine-grained groundmass of altered granite porphyry.

Massive quartz latite porphyry intrudes older sedimentary rocks in separated areas. At the head of Coyote Canyon an outcrop intersects the projected dip of well-defined bedding in micaceous siltstone of the Furnace formation where the two outcrops are separated by less than 15 feet of alluvium. A mile to the southeast, in the headwaters of Holcomb Creek (NE cor. sec. 36, T. 3 N., R. 1 W.), small intrusive apophyses of massive quartz latite porphyry are chilled against Furnace limestone (fig. 24).

Quartz Latite Tuff. Thin pods of tuff occur sporadically in massive and banded quartz latite porphyry. Associated with the elastic rocks in the bottom of Coyote Canyon are a few lenses, less than 10 feet thick, of fine-grained black massive tuff in which a few irregularly spaced feldspar crystal fragments occur. Nearby a somewhat coarser and lighter-colored lens of layered tuff is megascopically similar to the associated flow-banded quartz latite porphyry.

Intrusive apophyses of massive quartz latite porphyry in Furnace marble at the head of Holcomb Creek grade within a few inches to massive lithic crystal tuff (right of fig. 22).

Trachyandesite. Associated with massive quartz latite porphyry are a few thin dikes of dark gray vesicular trachyandesite. Two may be seen on the hill southwest of Coyote Canyon. Another, 5 feet wide, is exposed on the hill just northeast of the head of Holcomb Creek (fig. 24). It can be traced S. 65° E. for about 200 feet.

The north wall of the dike is separated by about 50 feet of shattered white marble from a nearly parallel 25-foot dike of granite porphyry. Where the marble screen disappears, the trachyandesite dike is cut by the granite porphyry dike.

Petrography

Quartz Latite Porphyry. Banded and massive facies of quartz latite porphyry are recognized. The mineralogy and texture of the two rocks are similar except for the fluxion structures that distinguish the banded quartz latite porphyry from the massive phase. Anhedral resorbed feldspar phenocrysts, as much as 3 mm long, make up from 5 to 10 percent of the rock. About half of these show albite twinning. Their composition ranges from oligoclase to albite. The plagioclase phenocrysts tend to form interpenetrating clusters (fig. 25). Less abundant potash feldspar phenocrysts are of about equal size. Quartz phenocrysts are rare. They are smaller than the feldspar phenocrysts and are usually resorbed.

Quartz, in angular fragments as much as 0.2 mm in diameter, may make up half the groundmass. The remainder, which has an undulatory extinction, is a cryptocrystalline aggregate of finer-grained quartz, sericite, and saussuritized feldspar. The specific gravity of the quartz latite porphyries ranges from 2.60 to 2.66.

Crystal and Lithic Crystal Quartz Latite Tuff. Tuffs that occur with quartz latite porphyry are of at least two structural types. The first type, a light gray, fine-grained crystal tuff has a megascopic layered structure resembling that of the flow-banded quartz latite porphyry with which it is associated. Crystal fragments of feldspar, as much as 3 mm in diameter, form about 20 percent of the layered tuff. A few of the fragmental feldspar crystals are interpenetrating and most of these show albite twinning. The plagioclase feldspar is chiefly calcic oligoclase,

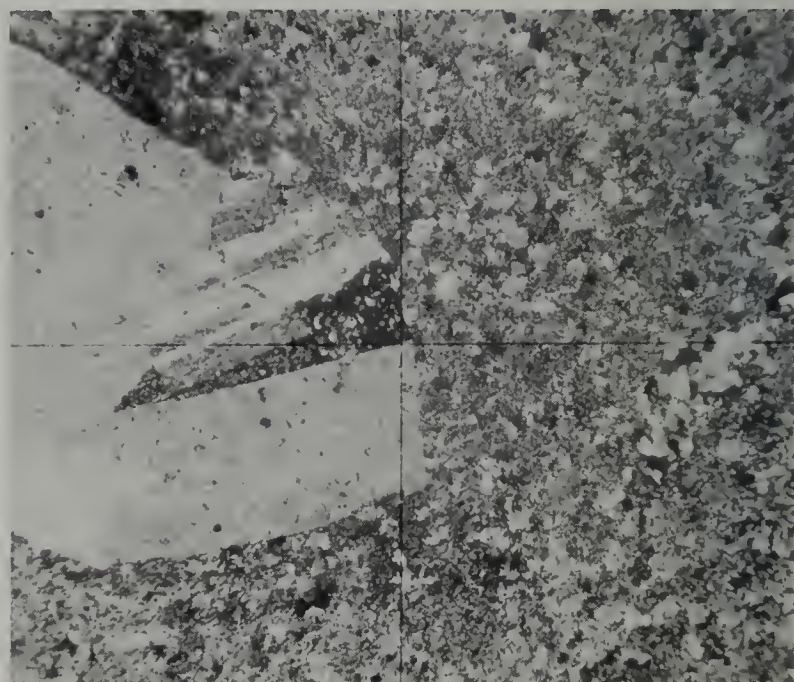


Figure 25. Photomicrograph. Banded quartz latite porphyry. Crossed nicols, x 12.

but a few albite crystals are present. Potash feldspar is somewhat less abundant than plagioclase. Quartz is rarely present as large crystal fragments, but it is abundant in the microspherulitic groundmass, which also contains potash feldspar, biotite, magnetite, apatite, rutile, and minor amounts of muscovite and epidote (fig. 26). In places the groundmass shows an alignment of crescentic shard-shaped particles into lenses molded around larger crystal fragments. The structure may have been caused by compression that occurred prior to crystallization, and the tuff may be a welded tuff.

The second structural type is a black massive tuff associated with massive quartz latite porphyry. It is made up of lithic and crystal fragments and has a well-defined vitroclastic texture. Some lithic fragments are irregular clasts, as much as 2 mm in diameter, with a microtrachytic fabric and minute albite-twinned plagioclase (oligoclase?) as the only recognizable mineral. Crystal fragments in the tuff, ranging from 0.2 to 1 mm in diameter, are chiefly oligoclase with some perthite, microcline, and minor amounts of quartz. The specific gravity of the tuff specimens from which thin sections were made ranges from 2.63 to 2.66.

Trachyandesite. This heavy dark gray rock in places contains enough magnetite to deflect a compass needle. The abundance of magnetite probably accounts for the high specific gravity of 2.75. Relics of amygdaloidal structure are preserved in the form of ovoids that average about 5 mm in the long dimension. The centers of the ovoids are now filled with biotite and irregularly rimmed with feldspathic material, which also fills minute fractures in the rock. Smaller amygdules contain quartz and clinozoisite with a rim of biotite.

The dark color, unusual weight and relics of amygdaloidal structure megascopically distinguish the trachyandesite from the quartz latite porphyry. Microscopically

the trachyandesite lacks phenocrysts of quartz and potash feldspar. Phenocrysts of oligoclase, ranging from 2 to 4 mm in length, lie in an altered trachytic groundmass dominated by subparallel laths of potash feldspar. Magnetite, calcite, epidote, apatite, flaky green biotite, and minor quartz are present in the fine-grained groundmass, and potash feldspar occurs intergrown with these minerals as well as in the sub-parallel laths. The percentage abundance of potash feldspar is difficult to judge and it may not exceed 10 percent of the rock.

Alteration. All of the volcanic rocks have been altered, but none of them show evidence of shearing or dynamothermal metamorphism. The igneous groundmass textures are preserved and the phenocrysts are not crushed. Amygdules in the trachyandesite are somewhat flattened but not sheared. A few of the plagioclase phenocrysts in the quartz latite porphyry have bent twin lamellae.

The most notable alteration product consists of flaky olive-green biotite usually associated with magnetite and sphene. In the quartz latite porphyry the biotite occurs in veinlets and also in clusters as much as 3 mm in length. These abut or surround feldspar phenocrysts. Veinlets of flaky green biotite also ramify through the crystal and lithic crystal tuffs and trachyandesite. In some places the veinlets bulge out into pockets about 1 mm in diameter which contain concentrations of magnetite as well as biotite. The origin of the biotite is uncertain. Where rarely seen with very fresh clean aggregate quartz and calcite, biotite appears to be of hydrothermal origin; in most places, the olive-green color suggests that it is a product of low grade metamorphism.

The feldspar phenocrysts almost without exception are clouded with sericite. Sericitized fragmental feldspars of the crystal tuff are in part cut by quartz vein-

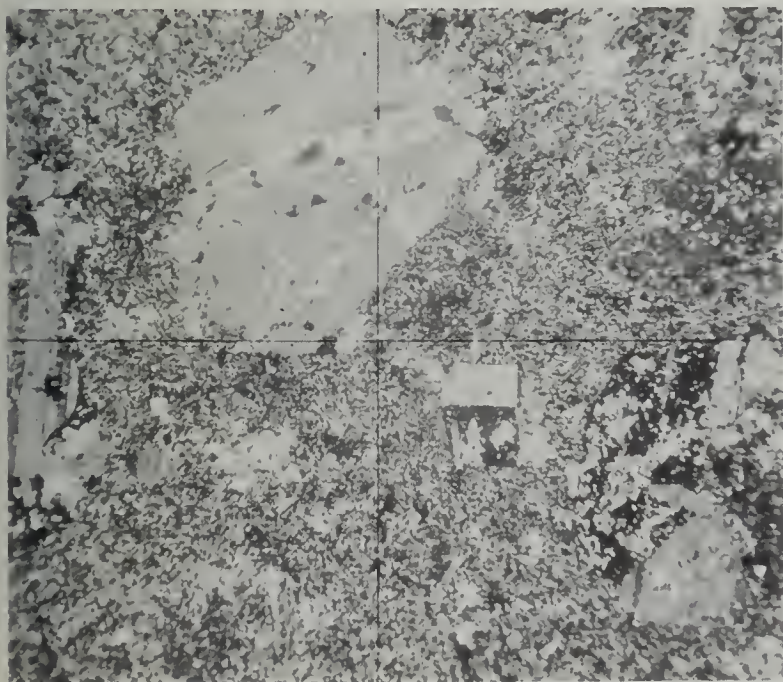


Figure 26. Photomicrograph. Quartz latite tuff. Crossed nicols, x 12.

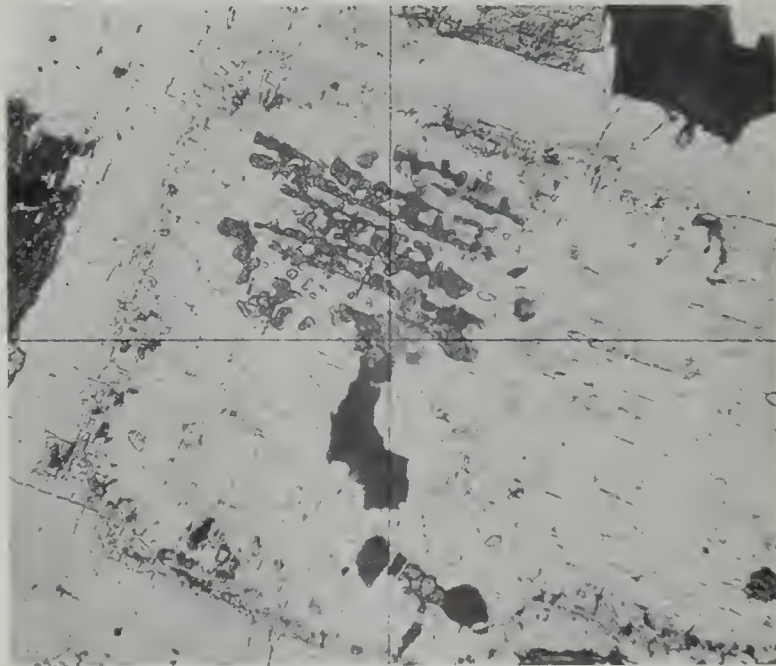


Figure 27. Photomicrograph. Intergrowth of hornblende and laboradorite in diorite. Ordinary light, x 12.

lets. Plagioclase phenocrysts of quartz latite porphyry are partly albitized. The turbid crypto-crystalline groundmass of the quartz latite porphyry locally contains saussuritized feldspar.

Mode of Occurrence

The close spatial and petrologic relationship between the metamorphosed massive and banded quartz latites, quartz latite tuffs, and trachyandesite in the porphyry complex implies a genetic relationship. Structural attitudes in the banded quartz latite porphyry agree with the northwestward trend of massive (not banded) quartz latite porphyry dikes. In Coyote Canyon the rock types seem to be gradational. The massive quartz latite porphyry in places clearly forms dikes that intrude the Furnace formation, but the banded rocks were not seen in contact with sedimentary rocks. Some porphyry masses occur as dikes that may have followed faults in the older rocks but the bodies are not themselves fault slivers.

The sporadic occurrence of tuffs in both types of quartz latite porphyry and the vesicular structures in the trachyandesite dikes indicate that all the volcanic rocks consolidated at or near the surface. The rarity of tuffs is an indication that most of the volcanic rocks were emplaced in liquid form.

If the volcanic rocks were emplaced at shallow depth they may have followed a more or less gaping northwestward-trending fissure system that opened in the older sedimentary rocks. Evidence for a former volcanic cover is suggested by larger exposures of migmatized volcanic rocks to the northwest.

Age and Correlation

In the mapped area the metamorphosed volcanic rocks are of post-Mississippian and pre-batholith age.

They are best correlated with the Sidewinder volcanics of similar petrology and Triassic(?) age described by Miller (1944) and Bowen (1954) in the adjacent Barstow quadrangle. Fifteen miles northwest of the mapped area the minimum thickness of the Sidewinder volcanics in the type locality in Sidewinder Mountain is reported to be 4000 feet.

Gabbro and Diorite

Distribution

The single small exposure of gabbro lies between Dry and Deep Canyons at an elevation of 4800 feet.

Half a dozen irregular masses of diorite are exposed west of Furnace Canyon on the north slope of the range. These bodies are gradational to granite cataclasite or are isolated by biotite quartz monzonite. Few measure more than a thousand feet in width, but some are as much as half a mile long. The highest mass of diorite is at an altitude of 7000 feet near the head of the east fork of Dry Canyon.

General Character

Gabbro and diorite are massive coarse-grained dark rocks very similar in appearance. They are composed of abundant hornblende in prisms as much as 5 mm in diameter and of somewhat smaller plagioclase crystals in about equal amount.

Gabbro. This rock is distinguished from diorite in the field only by the abundance of hornblende which comprises over half the minerals. The gabbro is unusually heavy (s.g. 2.95) due to the high content of hornblende. Veins of hematite and epidote as much as 2 inches wide occasionally cut the rock and these commonly dip steeply southward into the range front.

Diorite. In about half the exposures diorite is a fairly homogeneous coarse-grained massive rock, although the contacts with quartz monzonite are generally gradational. The rock in some small bodies is hybrid. Outward from the more mafic centers the rock is mixed with felsic material which is splashed through the host in the form of irregular sinuous fingers, lenses, and veinlets. In some places crosscutting felsic veinlets intersect at high angles. Displacement along the early veinlets indicates that the rock was brecciated before intrusion of the later veinlets. Even small hand specimens show a displacement greater than can be explained by dilation due to injection. This evidence may best be studied in good exposures in the northward-trending canyon in the center of sec. 12, T. 3 N., R. 1 W. Massive diorite there grades into somewhat schistose layers a few inches thick and as much as 20 feet long.

Diorite contacts with biotite quartz monzonite are not defined more closely than an irregular 50-foot zone in which hornblende gradually becomes a mineral of minor importance, and biotite, feldspar, and quartz become relatively more abundant. As diorite contacts are approached outwardly the relative abundance of felsic material increases. This probably fully accounts for the range in specific gravity of the diorite from 2.89 to 2.77.

Petrography

Gabbro. In thin section calcic plagioclase and hornblende dominate the hypidiomorphic granular fabric. Plagioclase makes up about 45 percent of the rock. The subhedral crystals average about 3 mm in length. They are zoned progressively outward and are complexly twinned. The plagioclase composition ranges from An 77 to An 52 and may average about An 60. Hornblende is only slightly more abundant than plagioclase and forms larger crystals, some of which are twinned. Pyroxene was not seen, but magnetite and sphene, as well as secondary epidote and chlorite are present.

Diorite. Selection of representative specimens of diorite is difficult because of the variable nature of the rock. Texture varies from coarsely hypidiomorphic granular to subophitic. Subhedral plagioclase, twinned and progressively zoned from An 55 outward to An 37, has an average composition of about An 40 and makes up 45 to 60 percent of the rock. Hornblende is in places intergrown with andesine (fig. 27). Rutilated biotite was seen as a partial replacement of hornblende in two thin sections, making up about 10 percent of one slide. Small amounts of magnetite, orthoclase, and interstitial quartz are present, as well as traces of sphene, apatite, and rarely uraltite.

Alteration. Gabbro and diorite have experienced about the same kind and degree of alteration. The plagioclase centers are incipiently saussuritized and hornblende is in part replaced by biotite, epidote, and chlorite. A minor amount of hornblende appears to be recrystallized in minute sub-parallel laths and clusters. The tex-

ture of the recrystallized hornblende resembles that of the deuterite hornblende discussed in the petrography of hornblende quartz monzonite. Rutilated biotite and, in one slice, apatite in needles cutting across boundaries of adjacent minerals, are additional indications of deuterite alteration.

Probable Origin of the Gabbro and Diorite

The bodies of gabbro and diorite are sufficiently similar in size, shape, position, and composition to suggest a common origin, but their relative isolation would indicate that they are not simply the exposed portions of a larger near-surface pluton. These small segregations of relatively high-temperature minerals could have formed as local centers of early crystallization in the batholith. Their positions, consistently below the highest elevations of the more acidic rocks, could be due to partial gravitational separation. The gradation from mafic centers outward to more felsic borders, the lack of sharp contacts with biotite quartz monzonite, and the internal evidence of deuterite alteration support this concept. Felsic material irregularly veined through some diorite could have formed during filter-pressing of the early crystal mesh or could have been contributed from later crystallizing biotite quartz monzonite. The mechanical brecciation of a portion of the diorite proves that partial crystallization locally preceded movement which occurred during feldspathization.

A replacement origin might be argued for part of the diorite on the basis of exposures where massive diorite grades to thin schistose layers. These rare, small outcrops, however, are here interpreted to have formed by local smearing of the early mafic crystals during the cooling process.

Age and Correlation

Inclusions of gabbro and diorite in biotite quartz monzonite prove their greater age. Gabbro and diorite are isolated from other formations by biotite quartz monzonite and granite cataclasite. The age relation to other pre-biotite quartz monzonite rocks is therefore not established. The composition of plagioclase feldspars indicates a higher temperature of crystallization for gabbro and diorite than for other pre-biotite quartz monzonite rocks of the area studied. These rocks, therefore, are thought to be the earliest of the plutonic rocks to crystallize.

In the Barstow quadrangle about 15 miles to the northwest, Bowen (1954) has reported that hornblende gabbro-diorite of pre-biotite quartz monzonite age intrudes the Triassic (?) Sidewinder volcanic rocks.

Tonalite Porphyry

Distribution

Tonalite porphyry is exposed in a small area due south of Holcomb Valley. West of Poligue Canyon it intrudes the Chicopee Canyon formation. East of Poligue Canyon the rock forms thin dikes and small plugs in Furnace marble. A similar relationship to Furnace marble was studied in the unmapped area south and east of Bertha Peak.

General Character

Structure. Evidence that tonalite porphyry is not of pre-tectonic age is shown by the map pattern (pl. 1). West of Poligue Canyon the rock occupies the crest of the eroded anticline in which quartzites of the Chicopee Canyon formation are exposed. The southeastern continuation of the anticline is lacking, which may suggest that faulting preceded or accompanied the intrusion. Effects of Recent tectonic movements are shown in the rather common development of unoriented fractures which are in places filled with loose soil (fig. 28).

Megascopic features. Where not fractured, tonalite porphyry is a structureless rock of fairly uniform composition. In about half the exposures the fine-grained rock contains a minor amount of sharply idiomorphic unoriented phenocrysts of plagioclase feldspar that average about 3 mm in length. Less commonly, smaller phenocrysts of hornblende are seen to occur. The development of phenocrysts is in general not related to contacts, but at a few contacts with Chicopee Canyon quartzites, tonalite porphyry is microcrystalline and phenocrysts are not megascopically visible. At the same contacts the intrusive rock commonly contains inclusions of massive white quartzite and black micaceous quartzite. The xenoliths have evidently been somewhat corroded and partly assimilated. In places tonalite porphyry is lobate into massive white quartzite xenoliths. Smaller inclusions of black micaceous quartzites commonly show thin rims of feldspathic material.

Petrography

The tonalite porphyry typically consists of plagioclase phenocrysts set in an altered microcrystalline groundmass of hornblende, biotite, plagioclase, and quartz. The original fabric is dominated by phenocrysts of idiomorphic plagioclase from 3 to 5 mm in length, twinned on the Carlsbad, albite, and pericline laws, progressively zoned from An 45 outward to An 10, and rimmed with orthoclase (fig. 29). The average composition may be An 30 to An 35.

Near contacts with quartzite small plagioclase crystals in the groundmass show flow structures. Near contacts with hornblende quartz monzonite an intergrowth of microcline and quartz may be seen to replace andesine phenocrysts and to attack margins of hornblende crystals in the tonalite porphyry. Quartz in the groundmass commonly forms myrmekitic intergrowths with plagioclase, or a micropegmatitic fabric with orthoclase.

The following percentages are estimates of average mineral abundance in 16 sections of the tonalite porphyry: plagioclase 50 percent, hornblende 15 percent, biotite 15 percent, quartz 10 percent, orthoclase 5 percent. Sphene, apatite, muscovite, epidote, and iron ore compose 5 percent of the rock as accessories or alteration products.

Alteration. Tonalite porphyry is somewhat metamorphosed. The original fabric is obscured by the development of olive-green biotite and epidote. Biotite has a flaky poikilitic habit and commonly shows a retrograde alteration to sagenite and sphene. Secondary sphene has developed around iron ore. Biotite in some sections partly replaces hornblende (fig. 30) and locally invades plagioclase phenocrysts. Plagioclase crystals are strained but not granulated.

Interpretation and Age

The tonalite porphyry lacks secondary foliation, is not granulated, and the associated dikes are not folded. Primary flow structures developed on a microscopic scale are confined to contacts. These facts suggest that the tonalite porphyry occurs as a post-tectonic intrusive induced by pressure to invade a favorable pre-existing structure. Subsequently the rock has experienced minor thermal alteration and still later possibly deformation associated with the late Cenozoic faulting.

Tonalite porphyry intrudes the Furnace formation, is preserved abundantly as inclusions in biotite quartz monzonite and rarely as xenoliths in hornblende quartz monzonite. The rock is therefore younger than the Furnace formation and older than the hornblende quartz monzonite, but its age in relation to volcanic



Figure 28. Fractured tonalite porphyry exposed at head of Paligue Canyon.

rocks or to the gabbro and diorite is not established. Evidence has been given for considering all of the plutonic rocks to be younger than the volcanic rocks. The composition of the plagioclase feldspars (sodic andesine) suggests a lower temperature of crystallization for the tonalite porphyry than for gabbro and diorite, and for this reason it is considered to be of a somewhat later age.

Hornblende Quartz Monzonite

Distribution

Hornblende quartz monzonite is used here to designate for the purpose of brevity a complicated granitic rock

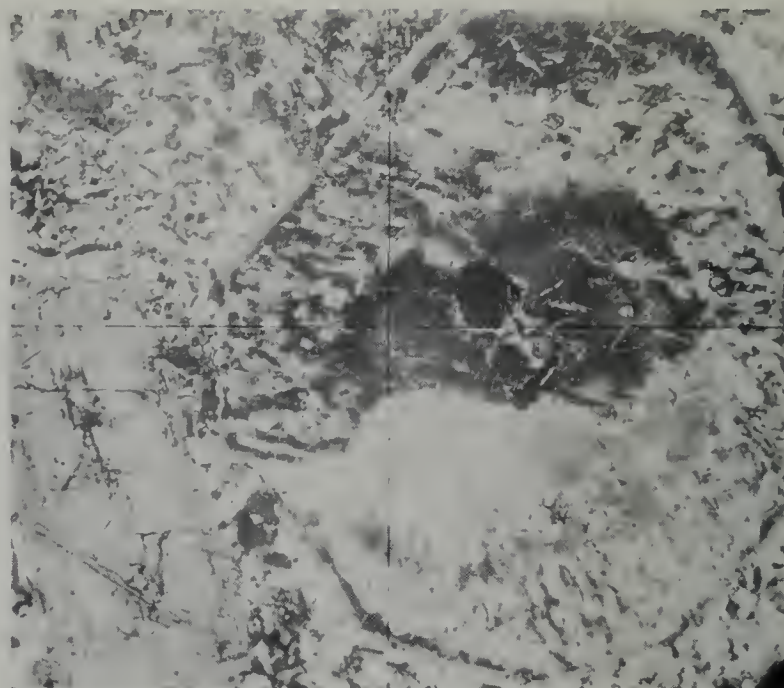


Figure 29. Photomicrograph. Zoned andesine phenocrysts rimmed with orthoclase in tonalite porphyry. Crossed nicols, x 12.

Figure 30. Photomicrograph. Biotite replacement of hornblende in tonalite porphyry. Crossed nicols, x 12.

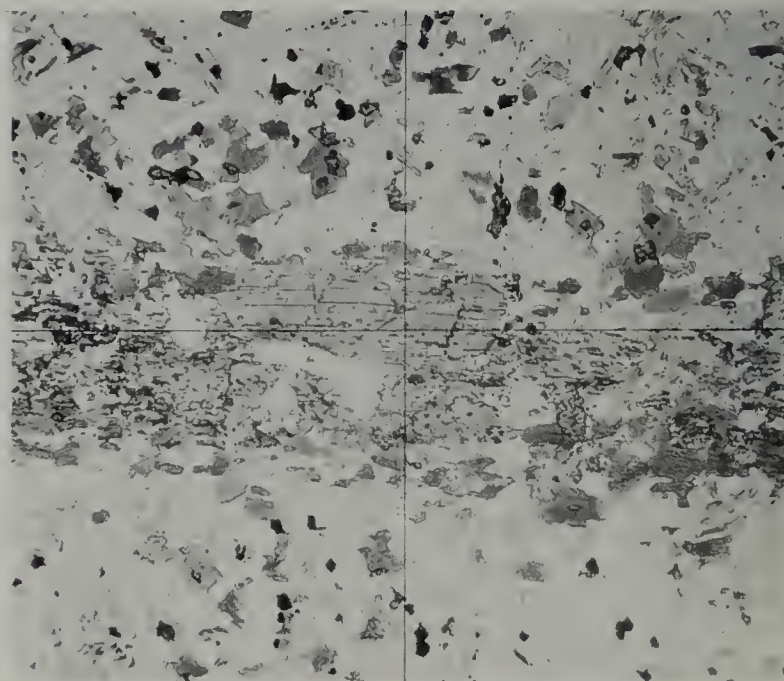


Figure 31. Hornblende quartz monzonite west of Holcomb Creek.



Figure 32. Gneissic hornblende quartz monzonite containing inclusions of blastomylonite (light color). West side of Holcomb Creek.

that grades continuously from hornblende quartz monzonite to hornblende quartz-bearing monzonite. The largest mass of this rock is a tabular body elongated to the northwest of Fawnskin. Smaller bodies of hornblende quartz monzonite are exposed in small pods in Poligue Canyon, east of Greenlead Camp, and in the extreme northwestern part of the mapped area, west of the mouth of Silver Canyon.

General Character

Structure. Foliation in the hornblende quartz monzonite is poorly and sporadically developed in zones as much as 200 feet wide near and parallel to contacts. It

Figure 33. Hornblende quartz monzonite (left) overlying mylonite. West side of Greenlead Camp.



is marked by a tendency toward common orientation in hornblende and, where present, large microcline crystals.

Zones of recent fracturing are visible in roadcuts and deep canyons. Due to poor exposures the trends of the zones are not traceable. Their considerable extent is indicated by the abundance of angular blocks and slabs that lie partly concealed by vegetation (fig. 31). The blocks have evidently been broken along earlier veinlets because they usually show a dark face thinly coated with hornblende or epidote. Veinlets filled with very fine-grained hornblende are commonly seen in outcrop. As many as half a dozen veinlets, each less than 1 mm thick, may be seen in some hand specimens. Usually no two of these are parallel.

Mylonitization and Protoclasis Associated with Forced Injection. The gneissic border in the northeast margin of the main mass of hornblende quartz mon-

zonite appears to be of primary origin. Unoriented fragments of blastomylonite are molded into the gneiss (fig. 32) just south of the contact with biotite quartz monzonite exposed on Holcomb Creek road. Westward from Holcomb Creek road, gneissic hornblende quartz monzonite grades into a 200-foot mylonitized zone traceable for a mile along a contact with biotite quartz monzonite that dips 30° to 45° southeast (structure section C-C'). The mylonite is well exposed on the west side of lower Greenlead Canyon where it is overlain by hornblende quartz monzonite (fig. 33). The underlying, younger, biotite quartz monzonite has also locally experienced granulation. Eastward from Holcomb Creek road, a thin screen of deformed Furnace marble separates hornblende quartz monzonite from biotite quartz monzonite (pl. 1). Deformation of the marble, intrusion, and mylonitization occurred prior to the formation of numerous veins of epidote, as much as an inch in width, which extend unbroken across the contacts between the intruding plutonic rocks and the marble screen. The field relations suggest that hornblende quartz monzonite which partly consolidated along the intrusive contact was mylonitized during completion of the injection of the main mass. Blastomylonite, preserved in gneissic hornblende quartz monzonite, shows that mylonite was brecciated and probably recrystallized while the margin of hornblende quartz monzonite was still sufficiently plastic to develop local primary foliation. A 50-foot strip of blastomylonite that separates hornblende quartz monzonite from biotite quartz monzonite in the roadcut just west of Greenlead Camp (sec. 28, T. 3 N., R. 1 W.) may have been recrystallized by the thermal effects of biotite quartz monzonite. Thin dikes that cut planar structures in the blastomylonite prove that mylonitization there preceded final consolidation of biotite quartz monzonite (fig. 34). Mylonitization and protoclasia along the northeast border of the large mass west of Holcomb Creek road is considered to demonstrate that hornblende quartz monzonite was emplaced syntectonically.

Lineation. In some outcrops lineation is developed as a consistent plunge of 1- to 3-inch folds. The few field observations made show no obvious regional trend.

Rhythmic Layering. A layered segregation of minerals is an interesting local feature of hornblende quartz monzonite exposed on the ridge west of Little Bear Peak (sec. 3, T. 2 N., R. 1 W.). Light and dark minerals there alternate in nearly horizontal bands about 6 inches thick that simulate graded bedding (fig. 35). The base of each layer is marked by concentrations of hornblende crystals aligned subparallel to the layering. Above the base of each layer biotite gradually appears and hornblende disappears. At the top of the layers only a few flakes of biotite appear in a coarse-grained feldspathic matrix.

Dikes. Near contacts the hornblende quartz monzonite is cut by pegmatite and aplite dikes. Pegmatites are abundant along the southwest contact in pod-like bodies of coarsely intergrown quartz and microcline as much as 50 feet long and 20 feet wide. More commonly pegmatites form veins only a few inches thick that fray out into the country rock (fig. 36). Aplite dikes are also generally a few inches thick, but they are somewhat thicker and more abundant along the northeast contact of the hornblende quartz monzonite.



Figure 34. Recrystallized mylonite west of Greenlead Camp.

Veinlets of epidote occur sporadically. Commonly the steeply inclined veinlets are a few millimeters thick. They cut aplite dikes and in places also cut pegmatites (fig. 36).

Megascopic Mineralogy. The quartz content of the hornblende quartz monzonite ranges from 2 to as much as 15 percent. The proportion of quartz is difficult to determine with a hand lens and usually it is impossible in the field to distinguish between monzonite and quartz-bearing monzonite. The really distinctive feature of the rock that serves to mark its boundaries is the persistent presence of from 15 to 25 percent of megascopic hornblende, which gives the rock a dark aspect. The hornblende occurs in dark-green prisms as much as 5 mm long, about half of which have light-green or brown centers. A few of the prisms are sharply terminated; but commonly they have ragged ends and some may be seen to fray out and connect irregularly with the thin dark fracture fillings of very fine-grained hornblende.

Potash and plagioclase feldspars are of about equal abundance and make up two-thirds of the rock in most exposures. There are variations, however, near contacts with biotite quartz monzonite which suggest that the monzonitic character of the hornblende quartz monzonite may be the result of microclinization. The north and east margins of the mass south of Holcomb Creek contain as much as 30 percent of pink or gray phenocrysts (porphyroblasts?) of microcline ranging from 1 to 5 cm in length. There is some increase in quartz and a corresponding decrease in size and abundance of plagioclase. The same development of large microcline crystals may be seen near contacts in small intrusive patches of hornblende quartz monzonite east of Greenlead Camp.

Coarse sphene is recognizable with a hand lens in amounts from 2 to 5 percent. Biotite is rarely seen to occur.

Petrography

The rocks recognized in this group grade from hornblende quartz-bearing monzonite to hornblende quartz monzonite. They include also mylonite from a thin zone at the north contact of the main intrusive mass.

Hornblende Quartz Monzonite and Quartz-bearing Monzonite. Under the microscope the fabric of the rocks varies from coarsely granitic to granoblastic. In some thin sections tabular feldspar crystals show a slight tendency to align with and segregate from hornblende prisms.

Quartz is present interstitially as 2 to 15 percent of the rock, increasing in abundance with potash feldspar.

Subhedral andesine-oligoclase crystals make up from 20 to 35 percent of the typically coarse-grained hornblende quartz-bearing monzonite. The plagioclase crystals are progressively zoned outward from calcic to more sodic composition and some show rims of microperthite. Plagioclase is commonly twinned on the Carlsbad and albite laws and has an average composition near An 27. Some oligoclase poikilitically encloses hornblende, sphene, and apatite. Most feldspars have irregular extinction under crossed nicols, and some are granulated. Remnants of albite-twinned oligoclase maintain optical continuity although in places isolated and replaced by late-crystallizing spongy potash feldspar.

Potash feldspar forms 30 to 40 percent of the hornblende quartz monzonite and it poikilitically encloses all other minerals: the accessories apatite, magnetite, and sphene, as well as hornblende, oligoclase, and quartz. Faint microcline lattices are visible in some potash feldspar. Elsewhere perthite is streaked and partly veined or graphically intergrown with quartz. In some sections this intergrowth replaces oligoclase.

The unusual hornblende that makes up 15 to 25 percent of the rock poikilitically encloses sphene, magnetite, and apatite, as well as oligoclase, microcline, quartz, and smaller crystals of hornblende. About half the hornblende crystals have irregular centers of diopside clinopyroxene.

The abundant unoriented veinlets of hornblende are important in the interpretation of the granoblastic texture of much of the hornblende quartz monzonite. These veinlets may be seen in thin section to cut microcline and oligoclase, as well as hornblende, and in places they are interbraided with similarly irregular trails of sphene. Some of the hornblende-filled veinlets contain fine-grained quartz and minor amounts of feldspar. Pale-green hornblende in the veinlets commonly consists of small rods 0.02 mm wide, elongated in the direction of the veinlet. In some thin sections the rods may be traced for a centimeter or more into porphyroblasts of hornblende as much as 3 mm long (fig. 37). The rock fabric is rarely displaced along the fractures filled by the hornblende crystals.

The specific gravity of these rocks ranges from 2.68, for the lightest hornblende quartz monzonite, to 2.79 for the heaviest hornblende quartz-bearing monzonite. The average of eight determinations is 2.72.

Mylonite. Mylonitized rocks are exposed along the contact between hornblende quartz monzonite and biotite quartz monzonite west of Holcomb Creek. Both sides of the contact have been locally mylonitized through a thickness of about 200 feet, and the following textural description applies essentially to the mylonites produced from the biotite quartz monzonite. The most common mylonite variant has a porphyroclastic texture (fig. 38). Quartz grains as small as 0.3 mm in diameter are in



Figure 35. Rhythmic layering in hornblende quartz monzonite. Ridge west of Little Bear Peak.



Figure 36. Lenticular pegmatite veins cut by epidote veinlets in hornblende quartz monzonite.

sutured contact in streaky aggregates and lenses 1 by 5 mm. Albite shows a similar development. The lenses are molded into a fine-grained groundmass in which microfoliation is defined by parallel alignment of quartz, feldspar, sericite, biotite, and opaques.

The mylonites in places show evidence of recrystallization. In blastomylonite thus formed quartz, biotite, and rare garnet occur as incipient porphyroblasts (fig. 39). The groundmass shows a typical orientation of anhedral grains of individual mineral species into lenses.

Late Alteration. The clinopyroxene centers of hornblende quartz monzonite and hornblende quartz-bearing monzonite are almost invariably veined with iron oxide. Most of the feldspar centers are sericitized and hornblende is incipiently altered to epidote and chlorite.

Structural Features Related to Origin

Mylonitization, fracturing, recrystallization, and late hydrothermal alteration have obscured much of the original character of hornblende quartz monzonite. Although the microtextures are complex the rock is considered to be of orthomagmatic origin for the following reasons:

(1) Small intrusive apophyses of hornblende quartz monzonite are chilled against Chicopee Canyon quartzite north of Fawnskin and in the vicinity of Greenlead Camp.

(2) The hornblende quartz monzonite in about half of 18 thin sections examined shows a hypidiomorphic granular fabric marked especially in the andesine-oligoclase crystals, which are twinned on the albite and Carlsbad laws and zoned progressively outward to more sodic borders.

(3) The layered structure west of Little Bear Peak (fig. 35) is interpreted as evidence for fractional crystallization by gravity separation in a liquid environment. A similar explanation has been proposed to account for small-scale rhythmic layering of feldspathic and mafic material in the Diana and Stark quartz syenitic complexes of the northwest Adirondaeks (Buddington, 1948, p. 27). In the Little Bear Peak exposures there is no evidence to suggest injection or intrusion of new material and it is difficult to explain the layering by any origin other than gravitational settling.

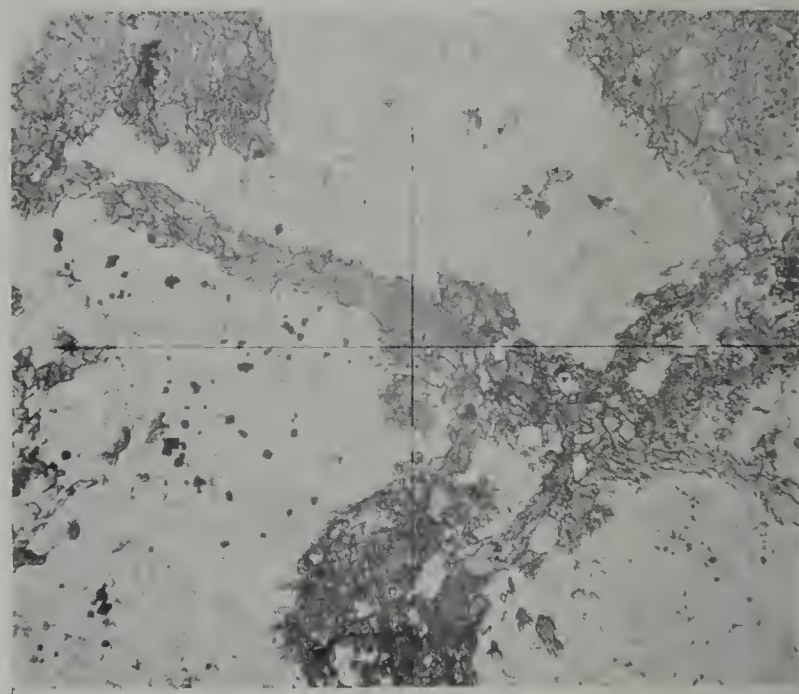
(4) The main mass of hornblende quartz monzonite locally exhibits protoclastic structures along its northern border. These structures have been cited as evidence of an intrusive magmatic body (Goodspeed, 1948, p. 57).

The relatively late crystallization of the spongiform phenocrysts of potash feldspar is evidently related to contacts with biotite quartz monzonite. The crystals may reasonably be interpreted as having formed from alkalic solutions contributed by the partly consolidated biotite quartz monzonite after the hornblende quartz monzonite had solidified.

Further explanation is needed to account for the unusual habit of the hornblende. Thin sections show that much of it crystallized later than oligoclase, microcline, quartz, and accessory minerals; yet hornblende commonly forms inclusions in large crystals of oligoclase and potash feldspar and, therefore, must have crystallized in part at a comparatively early stage. An explanation may be found in the veinlets earlier described in

which hornblende has apparently moved and recrystallized without destroying the original fabric.

Shand (1942) has described in the classic Cortlandt complex, New York, recrystallization of poikilitic hornblende when the rock was entirely solid. The process of hornblendization there was probably brought about by steam or hot solutions. Two of Shand's criteria for recrystallization apply to the hornblende quartz monzonite north of Big Bear Lake: (1) The feldspars show granulation, mortar structure, and irregular extinction, whereas the hornblende plates that ramify through this granulated base have in part escaped crushing and have retained normal extinction. (2) Hornblende in places is developed in fungus-like growths in clusters and aggregates of large crystals. In the area studied an additional criterion for recrystallization is that minute hornblende crystals actually may be seen to fill veinlets that connect with hornblende porphyroblasts (fig. 37).



It is suggested that the textures and structures in the hornblende quartz monzonite were developed in the following order. While partly crystallized, the main mass was squeezed upward by pressure from the southwest, forcibly injected into older sedimentary rocks, and locally thrust over early crystallized biotite quartz monzonite. Mylonitization and protoclasis occurred along the northeast contact with biotite quartz monzonite. Elsewhere nearly horizontal rhythmic layering of light and dark minerals (fig. 35) resulted from gravity settling after the main mass of hornblende quartz monzonite had been injected. Spongiform phenocrysts of potash feldspar could have developed metasomatically at this time. Fractures formed during further cooling served as channels for migration and deuteric recrystallization of hornblende and for upward migration of veins of epidote.

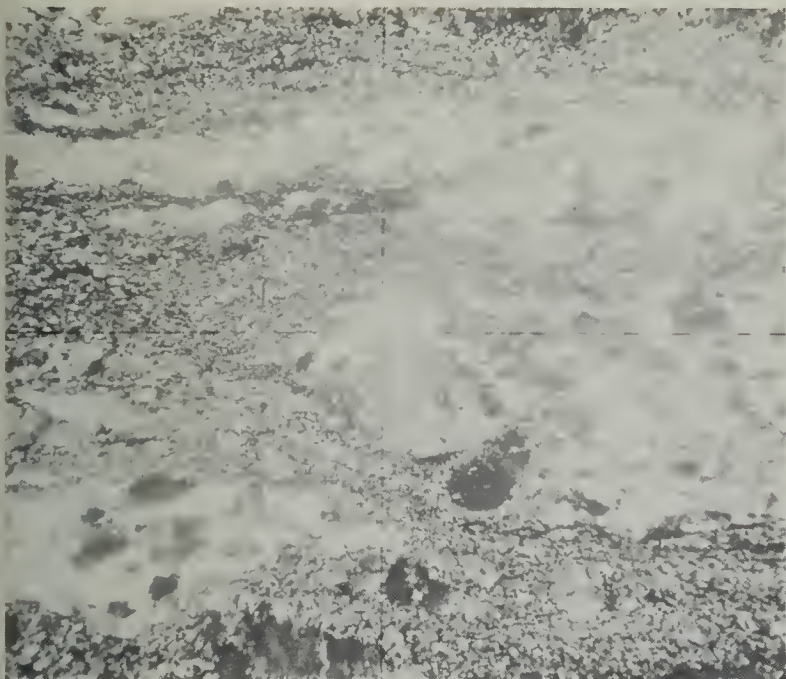
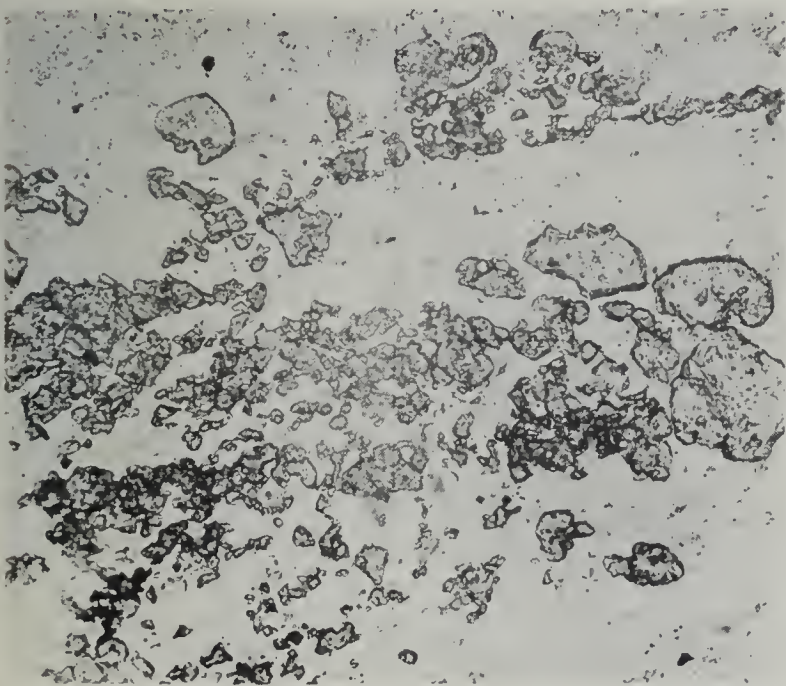


Figure 37 (left). Photomicrograph. Intersecting fractures in hornblende quartz monzonite filled with crystalloblastic deuterite hornblende. Ordinary light, x 12.

Figure 38 (above). Photomicrograph. Mylonite of hornblende quartz monzonite showing porphyroclastic texture. Crossed nicols, x 12.

Figure 39 (below). Photomicrograph. Garnet porphyroblast in blastomylonite. Ordinary light, x 24.



Age

The hornblende quartz monzonite cuts the older sedimentary rocks. It contains a few xenoliths of volcanic rocks and streaked out inclusions of biotitized tonalite porphyry. In places away from the northeast contact, hornblende quartz monzonite is cut by apophyses of biotite quartz monzonite and its final consolidation evidently preceded that of the main body of biotite quartz monzonite.

Granite Cataclasite

Distribution

Granite cataclasite is exposed along the range front between Crystal Creek and Dry Canyon, and west of Deep Canyon. The contacts grade to diorite, hornblende quartz monzonite, and biotite quartz monzonite. Typical exposures lie on the east side of the mouth of Dry Canyon and at the mouth of Crystal Creek Canyon. The rock is a structural rather than petrologic unit but is best described with the granitic sequence.

General Character

Notable features of the cataclasite are its fractured and shattered appearance and its dark dirty color. Uncemented fractures cut the rock without orientation; several directions of fracture may be seen in a single hand specimen. Other structures are rarely seen even in such steep bare-rock exposures as those near the mouth of Silver Canyon, where the relief is as much as 100 feet (fig. 40). However, dike-like bodies in places appear to have shared in the deformation. West of the head of Silver Canyon a crudely developed foliation dips into the range.

Outcrops weather to shades of dark brown or gray. Quartz and feldspar are recognized in some specimens with a hand lens and iron oxide fills some of the fractures.

A number of abandoned adits and shafts has been dug in cataclasite along the range front west of Crystal Creek. Most of these are less than 200 feet long. Weak post-deformation sulfide mineralization is shown in the walls and roofs of some adits in which cataclasite is cut by thin quartz veinlets which in places contain pyrite.

Petrography

All thin sections examined show a cataclastic texture and a few show relics of hypidiomorphic granular texture (fig. 41). Unoriented porphyroclasts of quartz and plagioclase, fractured and in places recemented are isolated in a mesostasis of the same crushed minerals and sericite. Plagioclase occurs in crystals from 0.5 mm to 2 mm in length which commonly show albite twinning, but it is so highly sericitized and albitized that the original composition is somewhat uncertain. Probably it was oligoclase. Plagioclase makes up about 30 percent of the rock. Microcline, usually less abundant, in some sections is equal to plagioclase. The quartz content ranges from 10 to as much as 40 percent.

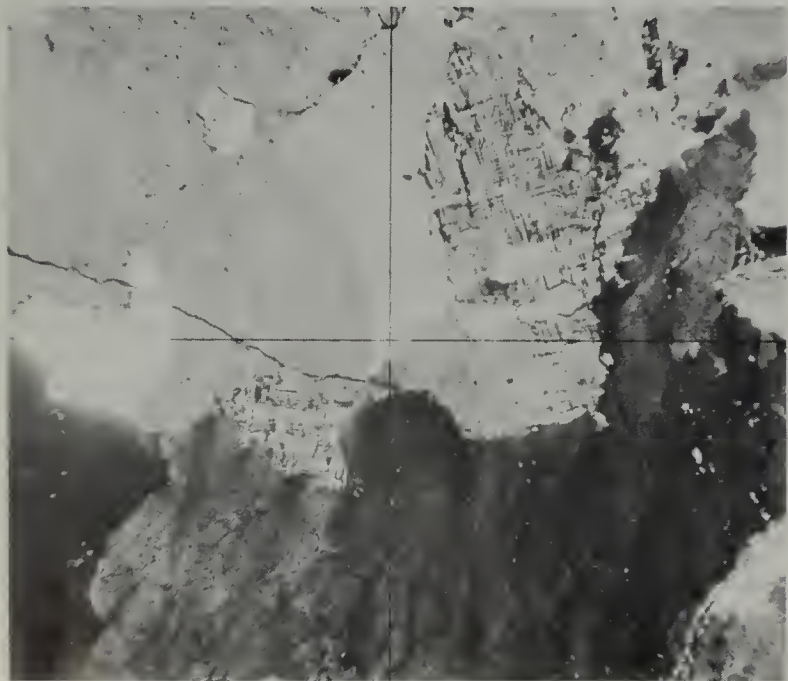
Sericite makes up 50 percent of some sections. It occurs chiefly in through-going fractures as much as 3 mm wide that cut or mold around the quartz and feldspar lenses.



Figure 40 (above). Granite cataclasite in west wall of Silver Canyon.

Figure 41 (below). Photomicrograph. Hypidiomorphic granular texture in least altered granite cataclasite. Crossed nicols, x 12.

Figure 42 (right). Photomicrograph. Hematite pseudomorph after pyrite in granite cataclasite. Crossed nicols, x 12.



Sericite veins that cut lenticular segregations of quartz and feldspar show that cataclasis preceded sericitization. Sericite therefore represents an initial stage of reconstitution of the rock following cataclasis rather than hydrothermal alteration of the original rock. Epidote is a less common vein mineral. Minerals of minor abundance include magnetite, calcite, biotite, muscovite, and sphene. The rare occurrence of euhedral hematite pseudomorphous after pyrite (fig. 42) in the clastic groundmass is evidence of post-deformation sulfide mineralization.

Interpretation

Deformation in the granite cataclasite did not reach the stage of mylonitization. Relics of granitic texture seen in thin section are the most important clue to the original character of this rock. The textural relics, however, could be from granitic dikes in a complex that originally included some volcanic rocks. The range in specific gravity from 2.68 to 2.60 is probably not significant in view of the altered condition of the cataclasite.

Deformation to cataclasite probably occurred during late Cenozoic thrust faulting along the range front and is considered in a later section of the paper dealing with structure.

Age

The age of the granite cataclasite is not known. Most of it evidently was derived from granitic intrusives of the upper Mesozoic sequence.

Biotite Quartz Monzonite

Distribution

Biotite quartz monzonite north of Big Bear Lake was originally mapped as "Cactus granite" by Vaughan and named for a locality 4 miles east of the margin of plate 1. The regional boundaries of the unit have not been delineated but rock of similar lithology is exposed over at least several hundred square miles in adjacent areas of the San Bernardino Mountains and eastern Mojave

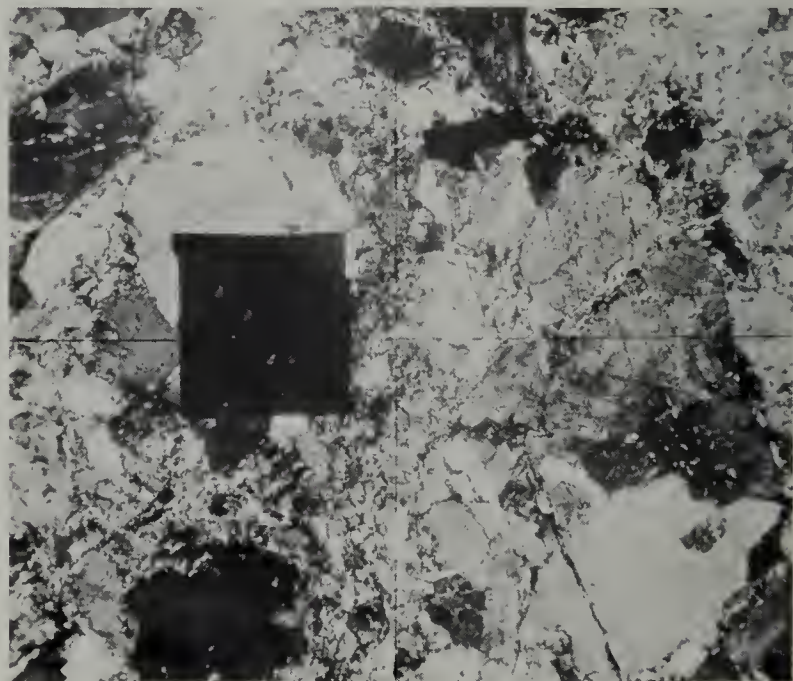




Figure 43. Jointing in coarse-grained biotite quartz monzonite near Grout Creek west of Fawnskin.



Figure 44. Medium-grained biotite quartz monzonite exposed in wall of Silver Canyon.

Desert. It is by far the most widely exposed plutonic rock in the area mapped for this report, forming a large mass in the extreme southwest corner of the Lucerne Valley quadrangle as well as smaller bodies to the northeast. Results of the present work agree with reports from other areas by Woodford and Harriss, Guillou, Hewett, and Bowen, that the "Cactus granite" comprises more than one phase and has an average mineral composition closer to quartz monzonite than to granite.

General Character

Structure. Foliation in biotite quartz monzonite occurs near contacts with older rocks. Jointing is the only internal structure commonly developed. Joint systems have exerted a topographic control in the southwest corner of the quadrangle where the most persistent joints trend about N. 45° W. with a variable steep dip (fig. 43). The main drainage (Grout Creek) follows the best developed joint trend. Nearly horizontal joints so closely spaced as to produce a sheet structure are exposed west of Furnace Canyon at elevations below 5500 feet.

Contacts. The contacts of the biotite quartz monzonite vary with the country rock but are commonly of three kinds:

(1) Contacts with older volcanic rocks; they are described in a later section dealing with migmatites of biotite quartz monzonite.

(2) Contacts between biotite quartz monzonite and other granitic rocks. They generally show some gradation. With granite porphyry, for example, contacts are so gradational and streaky that it is not everywhere clear whether the granite porphyry preceded or followed the intrusion of biotite quartz monzonite. The contact

with hornblende quartz monzonite west of Holcomb Creek is exceptional in that both rocks there show evidence of granulation prior to their final consolidation.

(3) Against marble the contacts are generally straight and concordant with bedding of the country rock. The concordant relation is well shown in large exposures west of John Bull Flat and Furnace Canyon. Actual contacts are so commonly concealed beneath talus that a fault relation might be suspected. However, the poor exposures are explained by greater resistance of the marble to weathering. Talus that conceals concordant contacts is generally composed of marble; where contacts are concealed by debris composed of biotite quartz monzonite, a fault relation can in some places be proved. Where good outcrops can be seen that extend a few feet away from nonfaulted contacts, the biotite quartz monzonite is not shattered, whereas it is shattered in areas of demonstrable faults.

Discordant dikes of biotite quartz monzonite too small to be shown on the geologic map generally trend northwest. Some larger discordant apophyses of biotite quartz monzonite crop out on the ridges east of Arctic Canyon and west of Furnace Canyon.

Dikes. Thin aplite dikes commonly cut biotite quartz monzonite. Epidote is less well developed in veinlets, some of which follow the centers of aplite dikes and are therefore of post-aplite age. On the east side of lower Furnace Canyon, sheared hornblende-biotite dikes, 1 to 3 feet wide, cut biotite quartz monzonite beneath the limestone overthrust. On the west side of Furnace Canyon large south-trending granite porphyry dikes cut Furnace limestone and in places, biotite quartz monzonite.

Mineral Variations of the Biotite Quartz Monzonite.

All the variants of the rock studied contain biotite as the principal and commonly the only primary dark mineral. Most of the biotite is dark green and makes up only about 5 percent of the rock. Albite-twinning can be seen with a hand lens in a third or more of the feldspars which predominate in the rock. Quartz occurs in amounts ranging from 15 to 40 percent of the rock.

Increase in quartz is accompanied by an increase in potash feldspar relative to plagioclase; a few exposures of fine-grained biotite quartz monzonite near contacts in Furnace and Arctic Canyons are gradational to granite.

Dark variants of biotite quartz monzonite are small in number and areal extent. Although hornblende is a relatively rare constituent of the rock, it is nearly as abundant as biotite in one exposure which trends eastward for about 2 miles across lower Poligue Canyon and ends near Big Bear Lake Ranger Station. The rock grades southward within a few hundred feet to more typical light colored biotite quartz monzonite. Hornblende also occurs sporadically in a few small outcrops of biotite quartz monzonite at elevations between 5000 and 6000 feet on the ridge between Crystal Creek and Dry Canyon and just west of Deep Canyon at 4800 feet. There the biotite content also increases to perhaps 20 percent, and gives the rock an unusually dark aspect.

Textural Variations. Biotite quartz monzonite exhibits a wide range of textures that grade into the common coarse hypidiomorphic granular texture. Typical exposures (fig. 43), in which individual crystals range from 5 to 10 mm in length, grade in places to a medium-grained, relatively resistant variant that shows allotriomorphic granular fabric (fig. 44). The change to finer grain size is accompanied by a relative increase in potash feldspar.

A porphyritic variant is locally developed in the John Bull Flat area and southwest of Hanua Flat where alkali feldspar phenocrysts of porphyritic quartz monzonite are as long as 2 or 3 cm.

Biotite quartz monzonite porphyry commonly grades to granite porphyry. Some microcline phenocrysts in the porphyry poikilitically enclose plagioclase.

Petrography

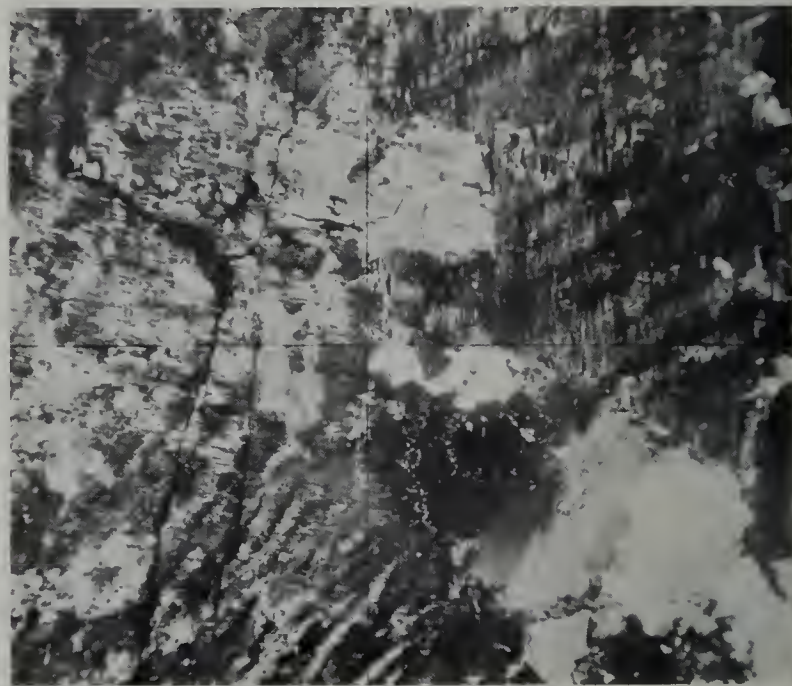
Thin sections of biotite quartz monzonite show variations in feldspar content as well as textural range.

The eastward-trending exposure in Poligue Canyon, in which hornblende occurs with biotite, has in part the composition of granodiorite. Potash feldspar is fairly rare in the coarse granular fabric. Most of the feldspar is andesine, complexly twinned, and in part zoned from An 47 to An 37. Other andesine crystals show oscillatory zoning. Interstitial quartz makes up about 20 percent of the rock; hornblende and biotite, each about 10 percent.

Plagioclase and potash feldspars each make up about a third of the commonly developed coarse massive facies of biotite quartz monzonite. The remainder is composed of quartz, biotite, sphene, apatite, and magnetite. Hornblende is rare. Plagioclase crystals are normally zoned. Rarely they are as calcic as An 40; more commonly, they are calcic oligoclase.

Potash feldspars are typically perthitic and have irregular boundaries. Patch and vein microcline-

Figure 45. Photomicrograph. Oligoclase replaced by microperthite in biotite quartz monzonite. Crossed nicols, x 12.



microperthite commonly surround and appear to replace plagioclase crystals. In some sections centers of homogeneous oligoclase crystals grade outward toward borders of microperthite, in which only ragged fragments of oligoclase are preserved in optical continuity (fig. 45). Other oligoclase centers have sharp microcline borders. Rarely the microcline borders are separated from oligoclase by a thin rim of quartz and perthite crystals may in turn be separated from each other by quartz rims.

Where the silica content is high textures suggest that late quartz has replaced microcline-perthite. Quartz patches may completely enclose microcline-microperthite, or irregular patches of quartz may maintain optical continuity although isolated by perthite. Micrographic intergrowths of quartz and microcline-microperthite are in some sections beautifully developed (fig. 46).

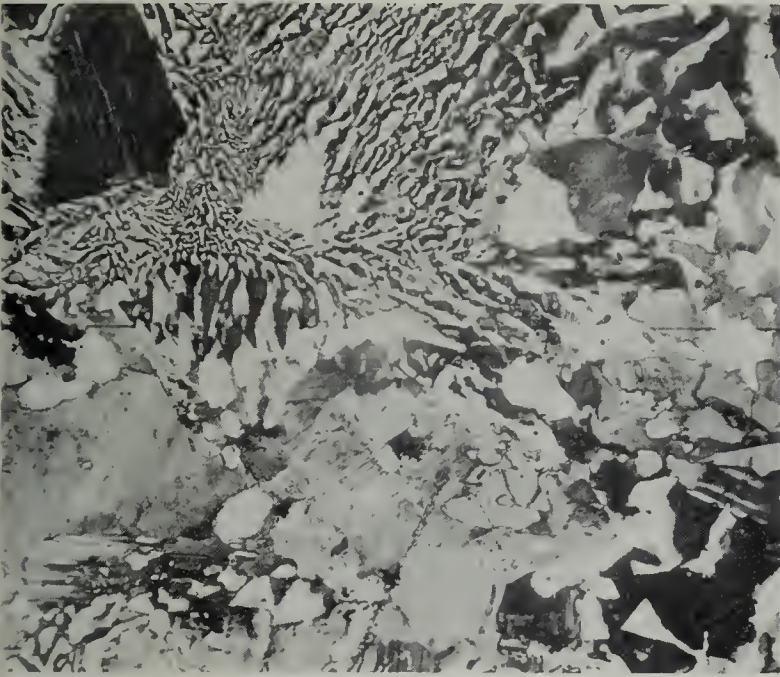
In the porphyritic variants of biotite quartz monzonite complexly twinned andesine crystals average about 5 mm in length and make up 20 to 50 percent of the rock. Some show oscillatory zoning; others progressive zoning from An 40 outward to An 18. Microcline-microperthite phenocrysts surround, embay, and separate plagioclase phenocrysts in the same thin section. Microcline and quartz in about equal amounts make up 90 percent of the microgranitic groundmass.

The average specific gravity of several samples of biotite quartz monzonite is 2.63.

There is no clear evidence in the 28 thin sections of biotite quartz monzonite examined that the development of perthite is related to the proximity of contacts with other formations. Perthite occurs as far as a mile from visible contacts with older rocks and persists to some contacts.

Alteration. Microcline-microperthite crystals are commonly clouded by very fine-grained individuals and aggregates of clear and colored minerals. In most thin

Figure 46. Photomicrograph. Micrographic texture in biotite quartz monzonite. Crossed nicols, x 16.



sections these dusty inclusions coarsen toward the crystal centers until they can be recognized as finely divided sericite and clinozoisite. Where alteration of borders has been most extensive, perthite centers are lost in thin section preparation. Plagioclase feldspars show an incipient saussuritization that extends across crystal boundaries where through-going veins of coarse epidote are present. In these sections plagioclase crystals are in part albitized and biotite is altered to sagenite and chlorite.

Origin of the Biotite Quartz Monzonite

The geologic map gives the best evidence that the broad structural relations of biotite quartz monzonite to older rocks are compatible with mass inflow of magma. Marble roof pendants nearly half a mile long, exposed on the ridge between Furnace and Crystal Canyons below 7,000 feet, have angular shapes that roughly match re-entrants in larger roof pendants to the south. These field relations suggest that biotite quartz monzonite was regionally emplaced by stoping. Only locally, as for example along the contact with hornblende quartz monzonite west of Holcomb Creek, is there evidence for forcible injection of magma.

Large scale differential movement accompanying stoping is not proved, although it may be suggested by the partial rotation of a large limestone xenolith west of the mouth of Furnace Canyon and similar twisting of blocks isolated northwest of Holcomb Valley. Right lateral displacement could have accompanied the intrusion of the biotite quartz monzonite along the southwestern boundary of the porphyry complex. A thin lens of massive white quartzite in the Furnace formation just east of Greenlead Camp may be correlated with a similar lens exposed a mile to the southeast (boundaries of secs. 25 and 26, T. 3 N., R. 1 W.). Skarn masses scat-

tered along the same contact are compatible with an intrusive origin. Large blocks of marble are in places cut across their strike by thin dikes of the biotite quartz monzonite or of the granite porphyry that forms a marginal variant of biotite quartz monzonite (sec. 24., T. 3 N., R. 1 W.). Brecciated fragments of marble enclosed in the margins of some of the dikes help explain the dikes as fillings in fractures that formed during stoping.

The geologic map shows that the largest masses of biotite quartz monzonite are concordant with bedding planes in the roof pendants. The relation suggests that preferred channels of entry were parallel to contacts and that stoping began by spalling off blocks along favorable sedimentary beds. Effects of contact and additive contact metamorphism described in the Furnace formation are compatible with magmatic intrusion.

In addition to the regional features shown by its relations to the other formations, the textural variants that grade from coarsely porphyritic centers to finer-grained borders suggest a magmatic origin.

In scattered areas in the northwestern part of the mapped area, residual masses of volcanic rocks locally suggest a metasomatic replacement origin for the biotite quartz monzonite. These are described later as biotite quartz monzonite of migmatitic origin. It should be emphasized here that it is principally the textures of the country rock that have been changed by the biotite quartz monzonite.

Age

The textural and mineralogical variants, not separately mapped north of Big Bear Lake because of their close areal relationship and gradational nature, represent different phases of biotite quartz monzonite. The different phases may not be very closely related in time.

Age determinations based on atomic disintegration are lacking for the intrusive rocks within the mapped area. Age dates by the lead method of 150 and 155 million years are reported for pegmatites enclosed by biotite quartz monzonite in the Pomona Tile quarry and in the Cady Mountains (Hewett and Glass, 1953). The localities are about 40 miles apart and 30 to 45 miles east and northeast of the mapped area, from which they are separated by faults.

Rocks of the San Bernardino batholith may prove to be related more closely in time to the batholith of southern California for which an average age determination by the lead-alpha method of 105 million years has been reported (Larsen et al., 1954, p. 1277).

Granite Porphyry

Distribution

Granite porphyry is most commonly developed in dikes and small plugs near contacts between biotite quartz monzonite and older rocks northwest and east of Holcomb Valley (fig. 21). The gradational streaky nature of some of the contacts with biotite quartz monzonite suggests that granite porphyry is in part a marginal modification of the principal rock of the batholith.

General Character

Phenocrysts of randomly oriented feldspar (as long as 5 mm) that make up as much as 50 percent of the rock, are the most distinctive feature of the granite

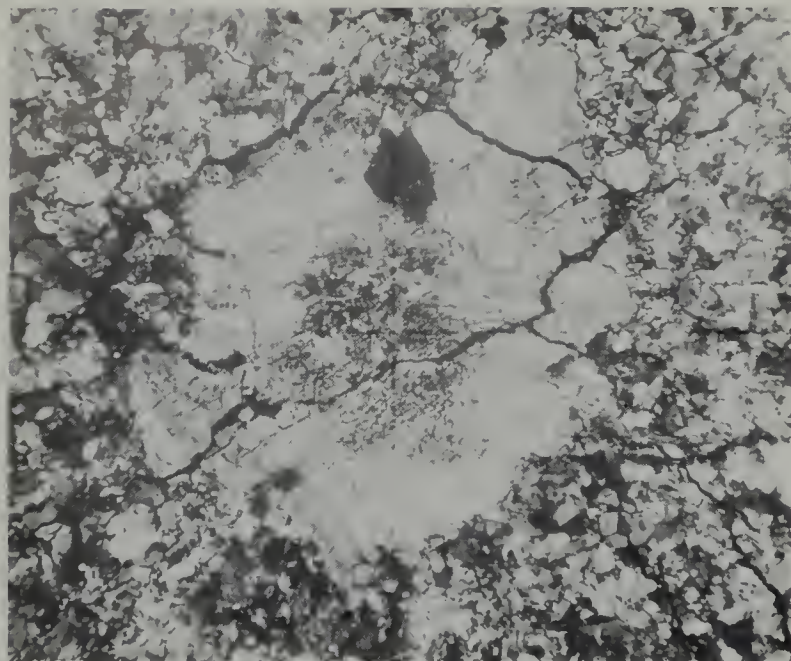


Figure 47. Photomicrograph. Oligoclase phenocryst rimmed with microcline in granite porphyry. Crossed nicols, x 13.

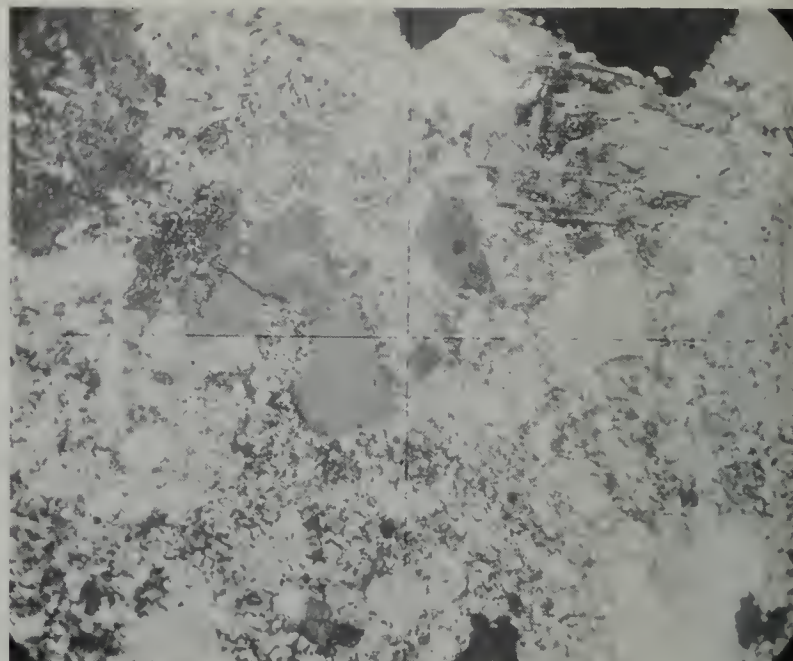


Figure 48. Photomicrograph. Oligoclase replaced by quartz (upper right) in granite porphyry. Crossed nicols, x 11.

porphyry. They are best seen near contacts with biotite quartz monzonite. Away from these contacts phenocrysts in the granite porphyry are smaller and constitute as little as 10 percent of the rock. The phenocrysts, which commonly show Carlsbad twinning, have a distinctive blue-gray color and are usually somewhat mottled. Most of them are oval; a few are sharply tabular. Quartz and biotite phenocrysts are rare although in some exposures biotite forms large clusters or aggregates of very small flakes. The groundmass of the granite porphyry ranges in color from putty-white to dark gray. In it magnetite, angular quartz, and very fine-grained biotite may be recognized with a hand lens.

Petrography

In thin section granite porphyry shows a well-defined porphyritic granular texture. The groundmass is a fine-grained but well individualized intergrowth of microcline-micropertthite and irregular quartz in which individual crystals rarely exceed 0.5 mm in length. Intergrowths of quartz and feldspar are abundant in some sections. Flaky olive-green biotite, magnetite, sphene, and apatite are the common minerals of the groundmass. Rarely hornblende is present. In smaller dikes and near contacts, the groundmass is commonly micrographic.

Phenocrysts in the granite porphyry, ranging from 3 to 5 mm in length, are set off sharply from the microcrystalline groundmass. In order of abundance they are microcline-micropertthite, oligoclase, quartz, and biotite. The somewhat corroded micropertthite phenocrysts are unusual for their variety. Some of them show an almost equal development of microcline and albite in irregular veins commonly subparallel to (010). In others, streamers of quartz appear to intrude and end in sharply angular blebs. Still others in the same sections have oligoclase centers sharply surrounded by micro-

cline rims. Oligoclase cores may dominate such phenocrysts or be preserved only near the center (fig. 47). Some oligoclase cores are completely surrounded and isolated from the micropertthite rims by an intermediate rim of irregular quartz. In still other phenocrysts the plagioclase cores are ragged and appear to be partly replaced by microcline that leaves isolated oligoclase in optical continuity. Again, quartz replaces oligoclase in areas where there is no development of microcline (fig. 48). Even the freshest feldspar phenocrysts contain some fine sericite as well as minute clear rods (apatite?), and equidimensional inclusions of barely visible colored minerals (magnetite and epidote?). In the more altered granite porphyries, these inclusions so cloud the phenocrysts that textural relations and feldspar composition are obscured.

Quartz phenocrysts in the granite porphyries are commonly corroded and embayed (fig. 48). The rare biotite phenocrysts contain a well-developed net of sagenite. The specific gravity of 12 specimens of granite porphyry ranges from 2.58 to 2.61.

Alterations. The secondary replacement textures of micropertthite and perthite in the granite porphyry could have resulted from unmixing following cooling and reheating. In the absence of reheating, according to Tuttle (1952, p. 114), micropertthite and perthite should appear only in small plutons whereas cryptopertthites would be expected in small hypabyssal dikes and sills. In the Lucerne Valley quadrangle granite porphyry commonly occurs in dikes less than 25 feet thick. Sanidine was not observed in 10 thin sections examined. Microcline and oligoclase, as well as perthite, occur as phenocrysts in granite porphyry dikes within 5 feet of contacts against marble. The microcrystalline groundmass of the porphyry indicates a rapid rate of cooling that may be incompatible with the formation of perthite unmixed by slow cooling. Prolonged reheating below

600°C may help to explain formation of the unusual perthites in the granite porphyries.

Other evidences of alteration in the granite porphyry consist of the change in hornblende, where present, to epidote, chlorite, and magnetite; development of sage-nite in the larger biotite crystals; and development of myrmekite in the groundmass. Flaky olive-green biotite is sporadically developed.

Age

Dikes of granite porphyry in places cut biotite quartz monzonite as well as migmatitic quartz monzonite. One dike contains brecciated fragments of a skarn rock evidently formed when the biotite quartz monzonite was emplaced. These examples are, therefore, the youngest igneous rocks known in the area. Textural gradations from granite porphyry to biotite quartz monzonite near other contacts with older sedimentary rocks indicate that granite porphyry was emplaced at nearly the same time as the main intrusive mass of the batholith.

Biotite Quartz Monzonite of Migmatitic Origin

Distribution

Irregularly shaped bodies of migmatite, ranging from a few hundred yards to perhaps a mile in length, are exposed along the range front west of Crystal Creek. Here older rocks are so thoroughly mixed with younger biotite quartz monzonite that the two types are not separable on the scale of 1:24000. Only the more intensely migmatized areas are shown on the map. Some xenoliths of older rocks are too small to be shown; others are so

nearly replaced that only subjective impressions can be had of their former presence and abundance.

It is necessary to emphasize that the boundaries of the migmatitic masses are gradational to coarse-grained biotite quartz monzonite. The migmatized rocks are variegated in structure and texture but the mineralogy is so similar to that of biotite quartz monzonite that textural criteria must be relied upon to distinguish between them. Boundaries shown on the geologic map are therefore highly indefinite.

General Character

The term migmatite has been defined in several ways. As used here, it refers to rocks in which a granitic component (commonly biotite quartz monzonite) and a metamorphic host are intimately mixed on a scale sufficiently coarse for the mixed condition of the rock to be megascopically recognized.

The structural types of migmatized pre-monzonite rocks commonly recognized are (1), a massive rock distinguished from biotite quartz monzonite by reason of its slightly finer grain size and porphyroblasts of biotite and plagioclase (fig. 49); and (2), a somewhat schistose rock of similar mineralogy. The two types are gradational.

The massive host rocks weather in shades of buff and light gray. Biotite in 3 mm flakes, spaced evenly through the fine-grained, sugary groundmass, typically forms 3 or 4 percent of the rock. Plagioclase is sporadically developed in anhedral crystals up to 5 mm in length. Poikilitically enclosed in them, rounded quartz grains

Figure 49. Pre-biotite quartz monzonite xenoliths showing planar structure. Ridge between Silver and Deep Canyons. Elevation 6500 feet.



Figure 50. Migmatite at 5000 feet between Dry and Deep Canyons. Biotite quartz monzonite cuts planar structure of older rock, which shows evidence of rotation.



may be seen with a hand lens. Similar grains of quartz make up much of the groundmass.

Planar structures in the second type of host rock are shown by a preferred orientation of porphyroblasts and by faintly developed color banding. Orientation of porphyroblasts is best shown in the alignment of biotite crystals, which range in size from 1 to 5 mm, but are likely to be of the same size in any one outcrop. They are commonly spaced rather evenly in the rock. Biotite makes up as much as 30 percent of small lenses in the layered rocks (fig. 50) but is usually less abundant. Plagioclase crystals show a more irregular development and distribution, but resemble the crystals of the massive facies in that they contain quartz grains. Color banding is rare. Where present, it is always parallel to the planar structures described. It is shown by slightly differing tints of buff and gray in layers a few millimeters thick. In some places these layers can be continuously traced for 5 or 6 feet. The color banding appears to reflect differences in abundance of felsic material. The host rock occurs in two contrasting relations to biotite quartz monzonite. In exposures on the ridge northwest of the Wright mine (sec. 16, T. 3 N., R. 1 W.), at an altitude of about 6,500 feet, migmatites are seen in resistant blocks varying in size from 2 to 50 feet long. These hard blocks lie half buried or tumbled together so that planar structures of separate blocks have a subparallel alignment in a coarse matrix of less resistant, deeply weathered biotite quartz monzonite. The intimate nature of the association of the two rock types may be studied in three dimensions in the hard blocks.

Most of the host rocks are interpreted as relics in part replaced by biotite quartz monzonite. The relics may, therefore, be termed skialiths (Goodspeed, 1947) and the mixed rocks, replacement migmatites. Biotite quartz monzonite commonly occurs within veins or laminae parallel to the visible or inferred planar structures of the skialith (fig. 49). These veins are not continuously traceable. Their terminations and borders grade imperceptibly into the fine-grained host. Veins of biotite quartz monzonite ordinarily fray out within a foot or two and disappear into the host. The width of the veins varies irregularly from a fraction of an inch to several inches in a single 6-foot exposure (figs. 49, 51). Streaky lenses of biotite quartz monzonite "bloom" across planar structures and lack visible connection with a larger area of quartz monzonite. Biotite quartz monzonite may also be studied in replacement dikes which show borders crenulated and scalloped into the skialiths (fig. 51). The unmatched walls of the dikes are extremely irregular. In the same exposures relic fragments fail to show the displacement expected by dilation (left, fig. 51).

Biotite quartz monzonite rarely crosscuts planar structure in the host; where it does the contacts are irregular and not sharply tabular. Crosscutting exposures of quartz monzonite are, however, thicker than the tenuous laminae that commonly form parallel to the planar structures. The rarity of crosscutting exposures may be due to the relative ease with which biotite quartz monzonite is weathered.

Chemical analyses of the migmatites are not available. The average mineralogy of the host rock and the biotite quartz monzonite is, however, so similar (as shown in 40 thin sections) that it is doubtful whether a signifi-

cant chemical change occurs across typical contacts of replacement migmatites. On the other hand, mineral variants within each unit indicate a range of chemical composition that would make difficult the interpretation of chemical changes across contacts. Good exposures of a second type of migmatites may be seen at altitudes between 4750 and 5000 feet across the northern boundary of sec. 9 between the mouths of Silver and Deep Canyons. There some of the host rock is finer grained and richer in mafic minerals than the relics described above. Exposures show that massive or somewhat schistose rocks have in places been broken up before or during intrusion. These rocks are considered to be "true" migmatites, because field evidence indicates that they originated according to the definition of Sederholm (1926, p. 136):



"... these hybrid rocks . . . look like mixed rocks, and they originated by the mixture of older rocks and a later erupted granitic magma, and therefore the term migmatite is the most appropriate."

The field evidence consists of structures interpreted as formed by shearing, kneading, brecciation, and rotation of the host rock during mixing of the younger biotite quartz monzonite. Megascopic evidence for shearing is shown in the lineation locally developed in the host rock. Lineation plunging about $20^{\circ}\text{S } 70^{\circ}\text{E}$ is marked by the persistent development of thin slivers a few centimeters long, oriented in the direction of plunge. The slivers weather and may be flaked from the host rock.

Kneading is suggested by the unusual development of massive biotite quartz monzonite in irregular, bifurcated rolls and tube-shaped lenses rather than in tabular dikes so that on plane faces perpendicular to the rolls, biotite

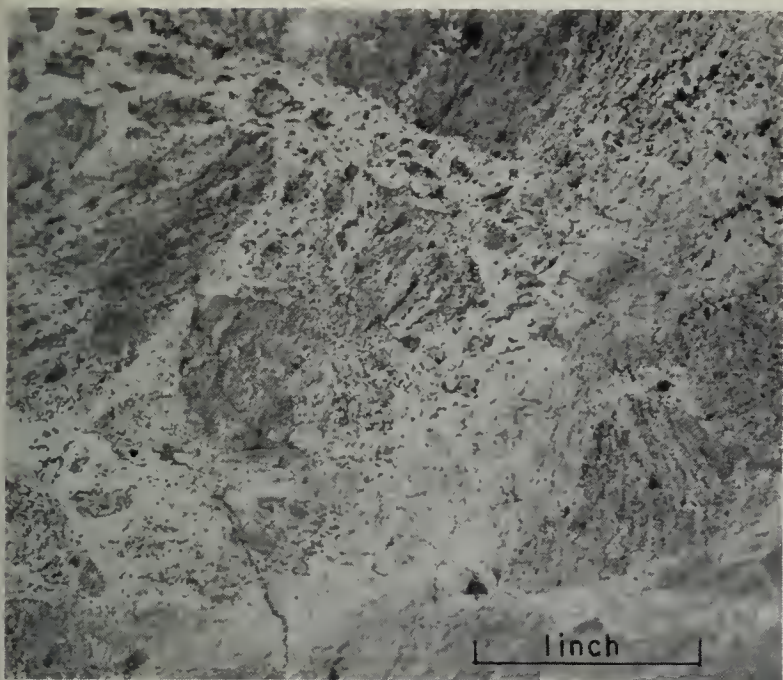
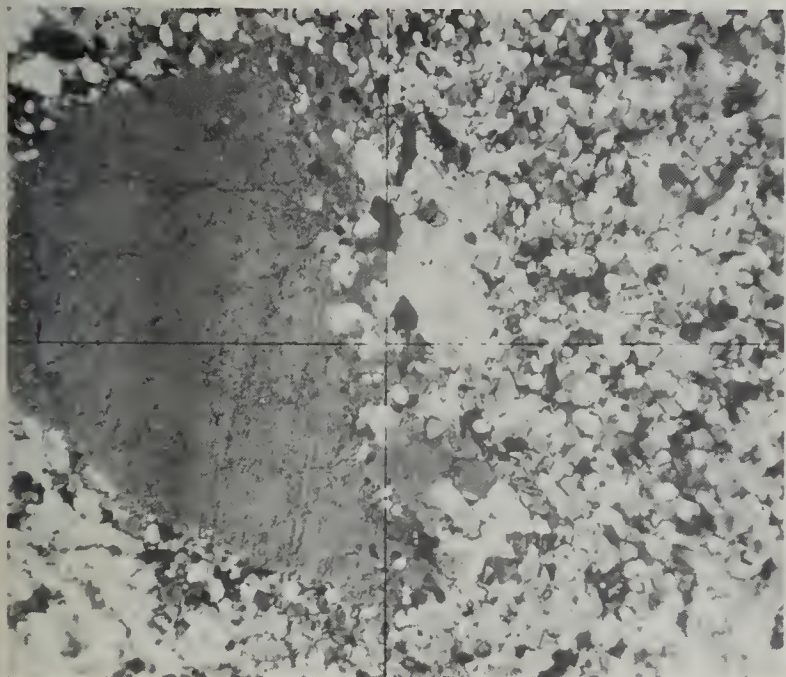


Figure 51 (left). Replacement dikes of biotite quartz monzonite. Ridge between Silver and Deep Canyons. Elevation 6000 feet.

Figure 52 (upper). Intrusian breccio on west side of Deep Canyon. Elevation 4750 feet. About one-third actual size.

Figure 53 (below). Photomicrograph. Migmatite of biotite quartz monzonite showing hornfelsic groundmass and quartz inclusions in margins of anhedral oligoclase. Crossed nicols, x 12.



quartz monzonite resembles a cluster of irregularly shaped and spaced saucers in the fine-grained host rock. Brecciation and rotation, proved by displacement and rotation of related fragments, can best be explained as an effect accompanying forcible intrusion (fig. 52). The centers of some aplite veins, 2 or 3 inches wide, that cut biotite quartz monzonite, are in turn cut by later epidote. Some of the veins have undergone pygmy folding.

Petrography

The mineralogy is generally the same in both structural types of migmatized rocks. The fabric, however, is variable and the specific gravity ranges from 2.62 to 2.68. Phenocrysts averaging about 3 mm in diameter commonly make up 20 or 30 percent of the rock. They are composed of oligoclase, microcline, and quartz in that order of abundance. Individual crystals in the fine-grained groundmass have an average diameter of 0.2 mm and may be over 50 percent microcline, followed in abundance by quartz, oligoclase, biotite, and hornblende. Magnetite, apatite, sphene, chlorite, sericite, and muscovite are usually present in traces.

The original porphyritic texture is masked by the effects of thermal metamorphism. Oligoclase anhedrons are in part porphyroblastic overgrowths. They enclose smaller crystals of microcline or oligoclase and their margins are peppered with somewhat rounded inclusions of quartz (fig. 53). They tend to grow in interpenetrating clusters as much as 6 mm in diameter. Some have well-defined borders that contain blebs of quartz but myrmekite was not observed. Veinlets of quartz as much as 0.2 mm in diameter, but commonly thinner, cut the oligoclase phenocrysts parallel, or at a small angle, to albite-twinning.

Less abundant phenocrysts of potash feldspar enclose quartz and oligoclase. Phenocrysts of quartz are fairly rare. Where present, they are about 1 mm in size, and are partly resorbed and embayed by microcline. Dark-green biotite forms in individual anhedrons as much as 2 mm in length which may be seen to enclose magnetite, chlorite, and epidote; more commonly biotite occurs in aggregates of small ragged flakes that in some sections form lenses as much as 4 mm long.

The altered groundmass of the migmatized rocks is a fine-grained hornfelsic aggregate of intergrown oligoclase, microcline, and quartz. Biotite and hornblende are locally abundant.

The contact between the replacement migmatites and biotite quartz monzonite is marked by an abrupt change in grain size from about 0.1 mm in the pre-granitic rocks to about 5 mm in the quartz monzonite. The plagioclase of the biotite quartz monzonite is somewhat more calcic (andesine-oligoclase) than that of the older rock. Biotite of the quartz monzonite shows a crystalloblastic tendency in the grouping of small flakes into larger crystals. Anhedral perthite phenocrysts of the biotite quartz monzonite in some sections are lobate into quartz and they also surround and isolate coarse-grained quartz. Some of the perthite crystals, as much as 5 mm in diameter, appear to be porphyroblasts.

Alteration. Sericitization has affected feldspars of both structural types of migmatized rocks. In a few thin sections the irregular feldspar phenocrysts show a

patchy development of sericite and muscovite in clouded areas 5 mm long that extend across crystal boundaries. Rarely sericite and muscovite are associated with through-going veinlets of quartz. Biotite in the groundmass is partly altered to epidote and chlorite.

Relation to Other Granitic Rocks

A few relics of banded rocks are preserved in hornblende quartz monzonite but they were not seen to occur in other rocks of the granitic series.

Volcanic Origin of the Host Rocks of the Migmatites

It was stated in the introduction to the igneous rocks that the migmatites are correlative with metamorphosed volcanic rocks exposed in the porphyry complex north-

resemblance to the cataclastic groundmass of the mylonites. It is concluded that planar structures in the migmatized rocks did not originate by shearing stress but as a result of primary layering.

Planar structures in the host rocks of the migmatites closely resemble similar structures in well-defined volcanic rocks preserved to the southeast in the porphyry complex. Faint color banding sporadically occurs in both rocks. Where planar structures are developed in the migmatites, they commonly have the same general north-westward trend as the banded volcanic rocks of the porphyry complex. Migmatized relics lie geographically between the volcanic rocks of the porphyry complex and those of the Barstow quadrangle exposed to the northwest. All the rocks are of pre-biotite quartz monzonite age.

The fabric, grain size, and mineralogy of the migmatites resemble the petrology of the volcanic rocks in the degree of spacing between planar structures; in the size, abundance, and habit of albite-twinned oligoclase phenocrysts, some cut by quartz veinlets, others sporadically developed in glomerophyric clusters; in the somewhat less abundant occurrence of potash feldspar phenocrysts; and in the appearance of resorbed borders where quartz phenocrysts are present.

Differences in texture and mineralogy between migmatites and volcanic rocks of the porphyry complex are such as might be expected if both were subjected to thermal metamorphism. The oligoclase phenocrysts of the migmatized relics are now in part porphyroblastic. Their irregular margins are crowded with fine quartz grains and they contain smaller crystals of microcline and oligoclase. Biotite has recrystallized into coarser grains. The fine-grained hornfels that now forms the groundmass of the migmatites has a mineralogy similar to the relic groundmass of the volcanic rocks to the southeast.

The mineralogy of the migmatites rules out any probable sedimentary antecedent other than an unusual meta-arkose. Arkose of such composition does not occur in the area. Quartzites of the Chicopee Canyon formation lack abundant feldspars and also have locally well-developed cross-bedded structure not found in the migmatized rocks.

For these reasons the migmatites are concluded to have been derived from volcanic counterparts of the quartz latite porphyry, quartz latite tuff, and trachy-andesite preserved in the porphyry complex to the southeast.

On the basis of field evidence in Coyote Canyon it was suggested that volcanic rocks were emplaced there as shallow dikes intrusive in older sedimentary rocks. Volcanic relics preserved as migmatites with biotite quartz monzonite are probably too widely distributed for such an origin and there is no probability of finding evidence to suggest that they were intrusive. The fine-grained texture of the groundmass favors crystallization at or near the surface. The migmatized volcanic rocks may be remnants of old flows that once roofed the batholith.

Age and Correlation

The host rocks of the migmatites are considered to be correlative with the volcanic rocks in the porphyry complex north of Holcomb Valley and with the Sidewinder



Figure 54. Sorted terrace deposits, west side of Crystal Creek ranch road.

west of Holcomb Valley. The evidence for considering them to be metavolcanic rocks is as follows.

Planar structures in the migmatites are relics that antedate the biotite quartz monzonite. The distribution of scattered outcrops indicates that planar structures in the host rocks were once developed over a wide area. Definitely sheared rocks in the area studied are confined to mylonitized zones at most a few hundred feet thick along the boundary between hornblende and biotite quartz monzonite. The fine-grained host rocks might locally be confused in outcrop with some of the mylonitized rocks, and the microtextures of the more highly metamorphosed migmatites show a similar, but less pronounced, segregation of minerals into lenses. The hornfelsed groundmass of the migmatites, however, has no

volcanics described by Miller (1944) and Bowen (1954) in the Barstow quadrangle about 15 miles northwest of the mapped area. The Sidewinder volcanics have a minimum thickness of about 4000 feet and are of Triassic (?) age.

Post-Batholithic Sedimentary Rocks

The post-batholithic rocks are a coarse clastic series of continental origin. They consist of conglomeratic sandstones of probable late Miocene or early Pliocene age, terrace deposits and talus breccias of Pleistocene(?) age, and alluvium. Brief descriptions are given here of exposures important to structural problems in the mapped area. Names of principal canyons that open at the range front are lettered in the north margin of the geologic map (pl. 1) to simplify reference to geographic localities.

Old Woman Sandstone

Distribution and Structural Relations

Recent erosion of older alluvium in a fault block west of the mouth of Arctic Canyon, has partly uncovered an arkosic conglomeratic sandstone that lies in reverse fault contact with Furnace marble. The base of the series is not exposed. Similar sediments lie beneath overthrust granitic cataclasite in the roadcut 500 feet west of Crystal Creek ranch house (SE $\frac{1}{4}$ sec. 11, T. 3 N., R. 1 W.).

General Character

West of Arctic Canyon the poorly bedded rocks have a minimum thickness of about 300 feet and are composed of lenticular conglomerate, coarse sandstone, and less abundant mudstone. In the upper part of the formation the rocks consist of subrounded pebbles, averaging about 3 inches in diameter, contained in a coarse sandy matrix that makes up 50 percent of the rock. About half the larger particles are marble; the remainder include biotite quartz monzonite, quartzite, and vesicular volcanics in order of decreasing abundance. Toward the base of the formation where the grain size is finer, thin mudstone lenses intercalate the sandstone. The relative abundance of marble pebbles decreases toward the base of the formation.

The small exposure under the thrust plate west of Crystal Creek ranch house is composed of layered and compacted but uncemented gravels (fig. 57). The latter strike N. 15° E. and dip 25° SE. Subangular pebbles in the granitic matrix average about 3 inches in length. They consist chiefly of biotite quartz monzonite with minor amounts of quartzite and marble.

Correlation and Age

The sandstone is closely related in lithology and occurrence to sediments that locally overlie biotite quartz monzonite in Blackhawk and Miles Canyons, 5 miles east of Arctic Canyon. Lithologic correlation is based on the occurrence of basic volcanic pebbles in both areas. Corroborating factors are the relative abundance of quartzite pebbles and granitic rocks in a matrix of finer grained sandstone, with occasional mudstone lenses.

Woodford and Harriss (1928) correlated the Blackhawk Canyon sediments with the Rosamond series described by Hershey (1902) for a type section in the western Mojave Desert, and concluded that the deposits in Blackhawk Canyon accumulated from the south in

pre-thrusting time (Miocene-Pliocene) under arid or semi-arid terrestrial conditions.

As to the conditions and time of origin, the present work agrees with Woodford and Harriss; however, Shreve (1959, pp. 15-18) has proposed a new formation name—Old Woman sandstone—for the rock unit and gives the following description:

Old Woman sandstone (To)—Small, patchy areas of massive reddish-buff conglomeratic arkose are exposed in many places along the lower slopes of Blackhawk Mountain from Surprise Spring to Arrastre Canyon. This sandstone is unique among the younger rocks because it is totally devoid of marble clasts. It is generally easily eroded and forms typical badlands topography. It is lithologically and stratigraphically identical to the "older desert deposits" reported by Vaughan (1922, p. 385) from near Cushenbury Springs west of the Blackhawk area and near Old Woman Springs east of it. This formation is herein named the Old Woman sandstone (a



Figure 55. Talus breccia in lower Poligue Canyon. Dark clasts are tonalite porphyry.

new name) and lower Blackhawk Canyon, the most extensive area of exposure, is designated the type locality. It is the oldest of the younger formations in the Blackhawk area.

Woodford and Harriss (1928, p. 274) and Richmond (1954, p. 124) correlated the Old Woman sandstone with the lithologically similar Rosamond series (Hershey, 1902, p. 365), a sequence of nonmarine sedimentary, pyroclastic, and volcanic rocks exposed in the Rosamond Hills in the western Mojave Desert. The name Rosamond has been applied to such a miscellaneous assemblage of Tertiary rocks in the Mojave Desert, however, that it has been rejected for use by the U. S. Geological Survey (Wilmarth, 1938, p. 1843). The name Tropico group is now applied to the original Rosamond near the type locality (Dibblee, 1958, p. 135). Inasmuch as no fossils have been found in the Old Woman sandstone, and it crops out over a limited area nearly 90 miles from the Rosamond Hills, correlation with the Tropico group (Rosamond series) appears questionable at best. For this reason the Old

Woman sandstone is treated in this paper as a separate formation.

The Old Woman sandstone rests in depositional contact on deeply weathered gneiss. The ancient erosion surface on which the basal sandstone was deposited had at least 150 feet of relief. It probably resembled the present gneiss terrane south of Surprise Spring, as it is almost certainly a slightly tilted and recently exhumed remnant of the same erosion surface.

The Old Woman sandstone becomes finer-grained, more massive, and less conglomeratic stratigraphically upward and geographically northward. The coarser facies of the Old Woman sandstone, which is well-exposed near the Voorhies fault in Blackhawk Canyon, is a massive reddish-buff to red-brown conglomeratic arkose consisting of a matrix of uncemented, poorly sorted, coarse-grained, angular fragments of quartz, feldspar, hornblende, magnetite, biotite, and other dark minerals in which are embedded subrounded to subangular pebbles and scattered cobbles of vesicular andesite, gneiss, quartzite, schist, vein quartz, and rhyolite (?), in order of decreasing abundance. All except the volcanic lithologies are exposed in the San Bernardino Mountains to the south. Clasts of marble are totally absent. A few resistant beds of coarse sandstone are partially cemented with calcite, but the arkose for the most part contains very little carbonate. Bedding in this rock is defined by thin layers of pebbles and by gradations in average grain size. Cross-bedding is rare, but where it does occur, it dips steeply northward between gently dipping bedding surfaces usually 1 to 3 feet apart. Filled channels are equally rare, and are usually small and inconspicuous.

The finer facies of the sandstone, which is best exposed near the mouth of Blackhawk Canyon, is a massive, practically unbedded yellowish-buff to brown arkosic mudstone composed of uncemented, slightly sorted, fine- to medium-grained fragments of quartz, feldspar, and weathered dark minerals. Interbedded with the mudstone are occasional beds 1 to 2 feet thick of poorly sorted, coarse-grained, calcareous sandstone, and of pebble conglomerate containing many subangular fragments of volcanic cinders and bombs and a few rounded clasts of gneiss and quartz-monzonite embedded in a fine-grained matrix. Calcareous concretionary amoeboid in shape and 2 to 30 cm. in diameter locally occur in the more massive mudstone and are usually distributed in planes parallel to the bedding. In the top 20 feet of the section and likewise roughly paralleling the bedding are discontinuous highly irregular layers 1 to 10 cm thick of a hard, white, aphanitic rock (tuff?) which forms sharp contacts with the enclosing mudstone. The mudstone contains no marble clasts and very little carbonate cement except within a few feet of the contact with the conformably overlying *Member 1* of the carbonate-rich Unshenbury Springs formation.

The Old Woman sandstone thins rapidly northward; in Blackhawk Canyon the thickness decreases from an estimated 600 feet near the Voorhies fault to a measured 200 feet near the mouth of the canyon 4500 feet to the north. In addition, bedding in the sandstone generally dips northward about 10 degrees more steeply than the Contact with the underlying gneiss; and cross-bedding, which is surprisingly rare, always dips to the north. These structural and stratigraphic features together with the lithologic character of the Old Woman sandstone suggest that it was deposited as an alluvial fan northward from the primordial San Bernardino Mountains under arid conditions similar to those now existing in the Mojave Desert.

Terrace Deposits

Distribution and Structural Relations

Along the range front from Dry Canyon to Arctic Canyon a dissected capping of cemented fragmental marble overlies weathered biotite quartz monzonite and granite cataclasite (fig. 54). A thin layer of the deposit unconformably overlies Old Woman sandstone just east of Arctic Canyon wash. The capping reaches a maximum thickness of 200 feet east and west of Bousie Canyon. It consists mainly of size-sorted and rudely bedded subangular marble slabs. The average length of fragments is about 1 foot, but the size ranges from 3 feet downward to the fine material that forms the matrix. Granite rocks probably compose less than 3 percent of the deposit. Imbricate structure locally developed in marble slabs indicates a current source to the south.

The surface on which the capping lies now dips about 5° NE. Differential movement on high-angle faults could account for the dip of the preterrace surface. The capping itself has been deformed by high-angle faults and cut by streams that drain northward from the principal canyons (see geologic map, pl. 1). Between Furnace and Dry Canyons remnants of sorted deposits, preserved 250 feet above the present stream, have gradients about half that of present streams. The source of the deposits between Crystal Creek and Dry Canyon has been removed by erosion.

Origin and Age

The nearly monomineralic composition of the terrace material shows that a change in conditions of sedimentation followed accumulation of the Old Woman sandstone. The change was evidently produced by thrust-faulting that brought marbles of the Furnace formation into positions of higher relief to the south and southwest. The terrace deposits in part overlie granite cataclasite (secs. 10 and 11, T. 3 N., R. 1 W.) and are clearly of post-thrusting age. They are cut by high-angle faults in several places west of Arctic Canyon and thus serve to separate two epochs of faulting.

Vaughan (1922 p. 392-393) included the bench deposits of the range front west of Marble Canyon in the regionally developed Heights conglomerates of Late Quaternary pre-glacial age. They are here considered to be of Pleistocene(?) age.

Talus Breccia

Cemented breccia deposits on the north side of lower Holcomb Valley, and north of Big Bear Lake east of Poligue Canyon, may have a minimum thickness of 300 feet. North of Holcomb Valley the rudely stratified rocks lie nearly flat. In Poligue Canyon the breccia dips about 20° to the south where it overlies deeply weathered biotite quartz monzonite. Rare fragments of igneous origin occur, but the breccia is over 95 percent marble (fig. 55). West of Poligue Canyon, quartzite fragments locally predominate over marble.

Although the talus breccias are rudely stratified, lack of sorting and imbricate structure distinguish them from the terrace deposits. The breccias are believed to represent deposits of rapid accumulation under tectonic conditions. Their age is uncertain but is probably close to that of the terrace deposits.

Alluvium

The alluvium is of two ages. Each unit is designated on the geologic map.

Older Alluvium

Older alluvium is exposed in Bear and Holcomb Valleys and at the foot of the range scarp. Differences in elevation and composition indicate that the deposits may be of varied ages. The problem has been discussed on a regional basis by Vaughan (1922 p. 384-393).

Patches of older alluvium preserved on the north side of Bear Valley appear to have been cut by Recent faults. There the alluvium consists of deeply weathered gravels in which rounded granitic and marble boulders and less abundant quartzite cobbles are as much as 15 inches in diameter in some places. In Holcomb Valley

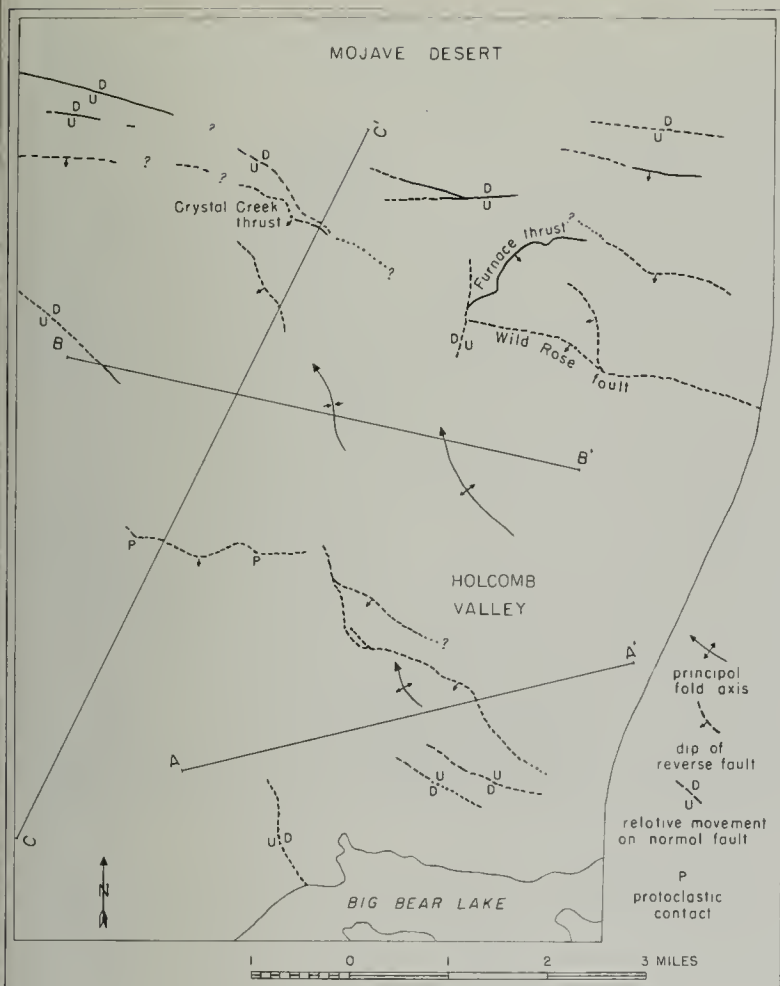


Figure 56. Outline map showing main structural features of the area studied.

older alluvium consists principally of deeply weathered massive quartzite and granitic rocks and small quantities of marble in a matrix of sand and gravel. The largest fragments rarely exceed 8 inches in diameter. A water well completed in October 1952 for the Hitchcock ranch in Holcomb Valley revealed a surprising thickness of older alluvium. The well is located on the west side of the road fork in the SE $\frac{1}{4}$ sec. 31, T. 3 N., R. 1 E. It is said to have penetrated 100 feet of gravel and an additional 200 feet of interlayered clay and gravel without striking bedrock.

Older alluvium at the foot of the range scarp occupies part of the floors of the major canyons and is locally preserved in thin veneers at higher altitudes to which it was displaced by recent faulting. The varied composition of the debris is not everywhere clearly related to source rocks now exposed to erosion. West of Deep Canyon angular slabs of massive white quartzite, in some places 2 feet in diameter, are mingled with the predominant granitic debris at elevations 100 feet above present stream bottoms. The quartzite boulders were evidently derived from the range to the south, but the source has been removed by erosion. Older alluvium between Deep and Dry Canyons is composed of deeply weathered granitic material in which rounded boulders of migmatized volcanic rocks and biotite quartz monzonite, as

much as 4 feet in diameter, lie in a coarse gravel matrix of the same material. Similar granitic material that lacks migmatized rocks makes up most of the older alluvium between Bousie and Arctic Canyons where marble is the present source rock. In Furnace Canyon angular fragments of marble are almost the only constituent of the older alluvium. These fragments range in size from fine material that forms the matrix to blocks that have exposed dimensions of 3 by 6 feet.

Recent Alluvium

Recent alluvium makes up the coalescent fans north of the range scarp and lies in beds of streams now actively dissecting older alluvium. Recent alluvium in streams that drain westward and southeastward from Holcomb Valley lacks the reddish yellow color that characterizes the older alluvium. The color of the older alluvium is probably due to oxidation of minor amounts of iron derived from the deeply weathered quartzite and granitic rocks.

STRUCTURE

Most of the structural features in the San Bernardino Mountains north of Big Bear Lake may be related to a west-northwesterly trend which evidently persisted until Pleistocene(?) time. A younger westerly trend is locally defined by faults along the range front. Generally poor exposures throughout the area and the absence of stratigraphic guides in the Furnace marbles limit observations of many structural details.

Pre-Tertiary Structure

The earliest recognized deformation occurred between Carboniferous and Triassic(?) time. Compressive stresses warped pre-batholithic sedimentary rocks into north-west-trending folds. Deformation did not produce foliation or linear structures in older rocks. Volcanic dikes of Triassic(?) age cut folds in Furnace marble northwest of Holcomb Valley. Old structures were partly preserved during intrusion of the later granitic series. South of Holcomb Valley tonalite porphyry intruded the crest of an anticline (pl. 1; fig. 56, sec. A-A'). West and north of Holcomb Valley hornblende quartz monzonite, biotite quartz monzonite, and granite porphyry intruded minor crests or troughs in folded Furnace marble. Syn-tectonic injection of hornblende quartz monzonite northwest of Holcomb Creek locally resulted in protoclasis and mylonitization along a south-west-dipping contact with biotite quartz monzonite (fig. 56, sec. C-C') and deformation of a screen of Furnace marble for a quarter of a mile west of Holcomb Creek.

Regional intrusion of igneous rocks destroyed evidence of any pre-batholithic faulting. The missing southwest portion of the anticline exposed south of Holcomb Valley, and the linear trend of volcanic dikes northwest of Holcomb Valley, could be explained by pre-intrusive faulting; whereas displacement of Furnace marble roof pendants probably accompanied regional intrusion of biotite quartz monzonite by stoping during Jura-Cretaceous time.

Late Cenozoic Structure

Renewed compression, perhaps from the south and southwest, resulted in two epochs of post-Miocene faulting. Thrust faults of pre-terrace age locally produced



Figure 57. Granite cataclasite thrust over Old Woman sandstone west of Crystal Creek. View east.

cataclasis in granitic rocks and sharp folding in Furnace marble along the range front at relatively low altitudes. High-angle faults are largely, perhaps entirely of post-terrace age. Many of the high-angle faults are steep reverse faults, upthrown on the south or southwest sides. A few vertical faults truncate structures in sedimentary rocks along the range front.

Thrust Faults

Crystal Creek Thrust. In a roadcut about 1000 feet west of Crystal Creek, at an elevation of 4900 feet, granite cataclasite is thrust over a thin sliver of Old Woman sandstone (fig. 57). The fault plane strikes about N. 65° W. and dips 30°-40° SW. An irregular zone of yellowish-white earthy gouge is exposed at the contact. The underlying conglomerate strikes N. 15° E. and dips 20°-25° SE.

The fault can be traced through cataclasite and shattered diorite for about a mile northwest to Dry Canyon wash; it may continue at a steeper angle as the southernmost of three sub-parallel faults mapped west of Dry Canyon. The Crystal Creek thrust or a younger high-angle fault may continue for a mile or more east of Crystal Creek Canyon. Landslides conceal exposures but the presence of a fault is suggested by several springs along a line marked by abruptly higher relief to the south (fig. 58).

Due to similarity of rock units in contact, there is little direct evidence for the extent of displacement on the Crystal Creek fault. The exposed horizontal component of overthrust is only about 100 feet. Granite cataclasite, associated with the thrust fault, occupies an irregular northwest-trending belt that averages about half a

mile in width and suggests considerably greater displacement.

Furnace Thrust. This fault forms the boundary between Furnace marble and biotite quartz monzonite for a mile northeast of lower Furnace Canyon. The contact is a gray gouge about 4 feet thick. The overthrust marble is crushed and brecciated as far as 30 feet above the gouge zone. Breccia in the crush zone ranges in size from small fragments to angular slabs as long as 2 feet. The underlying biotite quartz monzonite has been crushed and sheared for about the same distance beneath the contact. In a roadcut at the head of Bousie Canyon, four hornblende-biotite dikes, each about 2 feet thick and 50 to 200 feet apart, terminate at the sheared zone about 30 feet below the fault contact. Two of the dikes show boudinage structure below the shear zone.

The somewhat contorted gouge zone has no measurable dip in outcrop but the arcuate trend of the mapped contact reveals an average dip of about 5° SE.

The thrust disappears beneath older alluvium a mile northeast of Furnace Canyon. No brecciated zone was found in the elongated roof pendant west of Furnace Canyon and the consistent trend of bedding planes there contrasts with widely varying attitudes in the thrust plate east of Furnace Canyon. Thin tactite zones sporadically developed at contacts between marble and biotite quartz monzonite in the roof pendant west of Furnace Canyon indicate an intrusive, rather than a fault, relationship. However, exposures in the marble are partly concealed, and it is possible that the Furnace and Crystal Creek thrusts are the same continuous fault. The only



Figure 58. View southeast from elevation 5000 feet west of Crystal Creek shows topographic expression between Crystal Creek thrust (roadcut, lower center) and Wild Rose fault, the trace of which is represented by the canyon marked by arrow.



Figure 59. Recumbent fold axis in cherty black marble. North side of Wild Rose Canyon, 700 feet east of junction with Furnace Canyon.

measure of displacement on the Furnace thrust is the overriding of biotite quartz monzonite by Furnace marble for at least 1500 feet perpendicular to the strike of the fault.

Deformation Accompanying Thrust Faults. The name granite cataclasite was given to a unit of fractured, altered rock exposed west of Crystal Creek and described with the granitic sequence. Local gradation to diorite, hornblende quartz monzonite, biotite quartz monzonite, and possibly to metavolcanic rocks shows that granite cataclasite is a structural unit involving several igneous bodies that have shared a similar deformation. The deformation apparently focused along the Crystal Creek thrust. Preservation of bedding planes in weakly cemented conglomerate of the Old Woman sandstone, exposed beneath overthrust granite cataclasite, suggests that the sedimentary unit played only a minor part in the deformation.

Three widely separated, nearly recumbent, folds are exposed in the thrust plate east of Furnace Canyon. The crests are marked by thin layers of black chert (fig. 59). Sharp folds were not proved elsewhere indicating that these were probably produced during thrust-faulting.

High-angle Faults

Where an age relation can be established, high-angle faults prove to be younger than thrust faults. Thrust faults antedate the terrace deposits, whereas some high-angle faults cut terrace deposits along the range front.

Two groups of high-angle faults are distinguished. One group includes reverse faults that trend west or northwest, generally parallel to older structures. All the faults

in this group are downthrown to the north. The second group consists of vertical and normal faults, less well defined in trend, a few of which truncate older structures.

Reverse Faults. The Wild Rose fault is the most important of the group of high-angle reverse faults. In the canyon for which it is named, the fault apparently drops the dolomite lens in the Furnace formation at least 800 feet; the displacement is uncertain due to the lenticular nature of the dolomite. The fault strikes about N. 70° W. and dips 65°–75° SW. Southeastward from the mouth of Wild Rose Canyon the fault trace cuts obliquely up the range slope for nearly 4 miles. On the ridge west of Arctic Canyon pressure resulting from reverse movement along the Wild Rose fault apparently initiated the low-angle fault within the Furnace thrust plate. East of the head of Arctic Canyon a brecciated zone, 30 feet wide and locally marked by gouge, separates Furnace marble from biotite quartz monzonite for half a mile. East of the mapped area the Wild Rose fault cuts the south end of Burnt Flat. The fault was not demonstrated to continue west of Furnace Canyon.

Reverse faults exposed along the range front east of Furnace Canyon may be of minor displacement. The fault that strikes northwest across lower Arctic Canyon evidently drops the Furnace thrust beneath alluvium. The wedge of Furnace marble in reverse fault contact with Old Woman sandstone just west of Arctic Canyon wash is probably a fault sliver from the buried thrust plate. South of the westerly trace of the same fault, partly covered terrace deposits have anomalous southerly dips. High-angle faults west of Furnace Canyon are so poorly exposed that the direction of dip cannot every-

Figure 60. Marble roof pendant, west side of Furnace Canyon opposite Wild Rose tributary. Bedding is parallel to vertical jointing.



where be established. The map pattern indicates that faults between Crystal Creek and Dry Canyon, and between Deep and Silver Canyons, have steep southwest dips.

In the mountains to the south, the west-trending ridge that separates Holcomb and Bear Valleys is a horst elevated along two steep reverse faults north of the crest and along two normal faults south of the crest. The anticline east of Delamar Mountain was deformed and locally overturned to the northeast along the southernmost of the nearly parallel reverse faults. The northernmost of the two faults may continue in a southeasterly direction beneath alluvium along the south margin of Holcomb Valley.

Normal and Vertical Faults. South of the crest of the ridge between Holcomb and Bear Valleys two normal faults have relatively minor displacements, down to the southwest. Grout Bay, near the west end of Big Bear Lake, is a graben depressed between these and another normal fault displaced down to the northeast. Also in the highland area a nearly vertical fault, marked at the southeast end by silicification and at the northwest end by a crush zone, extends northwest across the head of Silver Canyon to the map margin. Its displacement is not known. Along the range front most of the normal faults trend west or west-northwest. A branching fault across the mouth of Furnace Canyon drops terrace deposits about 100 feet down to the north and truncates structures in a marble roof pendant. Between Crystal Creek and Dry Canyon a post-terrace throw of about 250 feet down to the north is shown by graded terrace remnants preserved on both sides of the fault north of the Crystal Creek thrust (fig. 56, sec. C-C'). The fault is covered by alluvium in Dry Canyon wash but is exposed again on the east side of Deep Canyon and continues to the western margin of the map. The steep fault that trends anomalously north along the east wall of lower Furnace Canyon drops the Furnace thrust and the Wild Rose fault down to the west.

Landslides

Critical exposures along the range front are commonly concealed by incemented marble or granitic talus. Landslide material can be distinguished from slope wash where small hummocks are locally preserved, or where debris consists of a mixed rubble of sharply angular fragments clearly not produced by residual weathering. The slide at the head of the east fork of Dry Canyon was evidently initiated when differential weathering of biotite quartz monzonite sapped the overlying marble. Slides between Crystal Creek and Furnace Canyon, however, and in some other areas, could have been initiated by movement on faults (fig. 58).

Deformation in Adjacent Areas

Persistent northwest trends characterize locally complex structures in the San Bernardino Mountains east of the mapped area. Pre-batholithic deformation in the Johnston Grade area (immediately east of the mapped area) included movement on thrusts and steep reverse faults that dip southwest, and formation of an anticline overturned to the northeast. The anticline and some of the faults were later intruded by biotite quartz monzonite. Late Cenozoic structures are dominated by a

northwest vertical fault and a reverse fault that dips 45° S. (Guillon, 1953, p. 13-15). Farther east in Blackhawk Canyon, two late Cenozoic thrust faults dip 19° - 23° SW. One is thrust over Old Woman sandstone. Later high-angle faults have predominantly north trends (Woodford and Harriss, 1928, p. 283-287).

West of the mapped area steep reverse faults of late Cenozoic age dip south-southwest along the north margin of the San Bernardino Mountains (Noble, 1926, p. 417).

Elevation of the San Bernardino Mountains

There is an average relief of about 4000 feet between accordant upland summits of the San Bernardino Mountains in the mapped area and nearly accordant summits of granitic peaks east and west of the town of Lucerne Valley in the Mojave Desert 6 miles to the north. Uplift along exposed vertical faults is insufficient to account for the discordance, but it has been suggested that a single large fault may be concealed beneath alluvium derived from a southward-retreating scarp (Vaughan, 1922, p. 396, 407).

The writer believes that the San Bernardino Mountains were uplifted chiefly along low- and high-angle reverse faults. Allowing an upward displacement of 800 feet along the Wild Rose reverse fault, and perhaps 700 feet along less important reverse and vertical faults to the north of it, about 2500 feet of relief still remains to be explained. The exposed thickness of 2000 feet in the Furnace thrust plate (pl. 1) evidently accounts for at least half the elevation of the range between Furnace and Arctic Canyons by thrust-faulting. The thickness of the Crystal Creek thrust plate has not been established, but continuous exposures of granite cataclasite, considered to have been fractured chiefly by thrust-faulting, have a relief of 750 feet.

SKETCH OUTLINE OF GEOLOGIC HISTORY

In pre-Carboniferous time, sandstones of the Chicopee Canyon formation were deposited in shallow water on a floor now destroyed by intrusion. The conformably(?) overlying Furnace formation was deposited chiefly as limestone during Mississippian, and possibly Pennsylvanian, time.

Later the limestone was dolomitized and locally silicified; and both of the older sedimentary formations were compressed into open northwest-trending folds.

Volcanic eruptions of Triassic(?) age cut structures in the Furnace formation. The trend of preserved volcanic relics is northwestward toward the adjacent Barstow quadrangle where rocks of similar age and composition have a minimum thickness of 4000 feet. North of the Big Bear Lake volcanic rocks probably formed part of the roof of the batholith.

The older sedimentary and volcanic rocks were intruded and metamorphosed during Jura-Cretaceous time by a sequence of plutonic and allied rocks including gabbro, diorite, tonalite, prophyry, hornblende quartz monzonite, biotite quartz monzonite, and granite porphyry.

In Miocene-Pliocene time the batholith was exposed in a region of moderate relief and the granitic rocks contributed detritus to the conglomeratic Old Woman sandstone. Probably during Pliocene time cataclasite was thrust northward over Old Woman sandstone, and

Furnace marble was thrust over biotite quartz monzonite. Debris, eroded from marbles brought into higher relief by movement on thrust faults, formed terrace deposits of Pleistocene(?) age along the north front of the range and talus breccias on the rising upland surface.

Later the range front was further elevated along northwest-trending high-angle reverse faults. Some of the faults cut terrace deposits. South of Holcomb Valley a fault block was elevated. Depression of the south part of the block along normal faults left the westward-trending ridge that now separates Holcomb and Bear Valleys.

Along the north front of the range, the south side of Holcomb Valley, and the north side of Bear Valley, older alluvium in some places conceals high-angle faults and in other places is cut by them. Rejuvenated northward-flowing streams have deeply dissected the terrace deposits at the front of the range.

MINERAL RESOURCES

Introduction

In May 1860, William F. Holcomb discovered placer gold in the valley that was later named for him. The diggings were generally shallow and easily worked. The richest deposits were found in Upper Holcomb Valley where the boom camp of Belleville recorded a voting population of nearly 100 in November 1860. In the State election of September 4, 1861, more than 300 votes were cast in Belleville precinct as compared to 959 votes for all of San Bernardino County (Holcomb, 1900). The *Mining and Scientific Press* (vol. 2, no. 43, January 4, 1861) reported "we are informed that there was great excitement in San Bernardino, last week, because of the recent discovery of rich diggings in Holcomb Valley . . . we are credibly informed of some parties making 50 dollars a day with a rocker". The *Los Angeles Star*, quoted in the *Mining and Scientific Press* (vol. 4, no. 22, February 15, 1862) reported "a large number of placer claims are being worked . . . there were about 100 men in the mines . . . the average amount of gold obtained from the placer diggings ranges from 5 to 15 dollars a day to the man". Later the *Mining and Scientific Press* (vol. 9, no. 2, July 9, 1864) reported "late intelligence from there states that a large amount of work is now in progress; a number of lodes are being opened".

The richer known placers, however, were soon exhausted and, handicapped by the scarcity of water, Holcomb Valley was again nearly deserted by 1880. Later the Holcomb Valley Company, Ltd., an English concern, unsuccessfully developed the placers from the late 1880s to 1894. The area has been intermittently worked since and was last seriously mined during 1933-41 by the Holcomb Valley Placer Company. A few abandoned cabins stand on the old placer sites (fig. 70) and one placer (Lee Placers) is intermittently in operation, but the current economic activity of Holcomb Valley is limited to the summer grazing of cattle.

Scores of idle adits, shafts, and pits in the highlands and north slopes of the San Bernardino Mountains attest to the search for primary metallic deposits. The known occurrences of metallic minerals including gold, silver, lead, zinc, iron, manganese, and tungsten and the non-metallic deposits of the area are described in the accompanying tabulated list. Some of the claims for metallic

minerals have been operated extensively in the past; but all of them have been non-productive for at least 15 years, some for more than 50 years, and their past production was not determined by the writer. Intermittent development work and exploration, however, on a small scale continues at some properties. The nonmetallic minerals of the area, especially limestone and dolomite, were being actively explored during 1958.

Metals

Lode Gold

Primary gold deposits in the mapped area have been extensively explored since their discovery nearly 100 years ago, but recent activity has been mostly small scale prospecting. During 1958 the most active exploration was at the Independence mine No. 1 (no. 16, fig. 61) but there was no production. Gold claims have been located in nearly equal numbers in three geologic types of primary deposits in the Holcomb area.

1. Mineralized shear or fracture zones in quartz monzonite:

Typical examples of fissure fillings in thin shear zones occur at the Wright mine (no. 33, fig. 61); Harvey K mine (no. 13, fig. 61); Ozier mine (no. 25, fig. 61); and Osborne mine (no. 24, fig. 61). Rarely, free gold is recovered from small pockets in thin shear zones (Alvin Linder, owner-operator of Wright mine, personal communication, 1953). More commonly gold is associated with hematite or pyrite although chalcopyrite, galena, and sphalerite occur in small quantities. Thin sulfide and hematite lenses are reported by local residents to have been encountered in the Harvey K and Ozier mines.

2. Mineralized fault contacts:

Numerous shafts and adits are distributed along thrust fault contacts between carbonate and plutonic rocks in lower Furnace Canyon (sec. 18, T. 3 N., R. 1 E.) and west of Crystal Creek Canyon (sec. 11, T. 3 N., R. 1 W.). More extensive workings, as judged by tailing piles such as that at the Gold Button mine in lower Silver Canyon (no. 10, fig. 61), followed faults in granite cataclasite.

3. Mineralized contacts between carbonate rocks and plutonic intrusive rocks:

The Greenlead mine (no. 11, fig. 61) is perhaps the oldest (patented 1876) and largest of operations at intrusive contacts into the Furnace formation. Although the adit was re-opened and cleaned to a length of 370 feet in 1953, no ore body was discovered and the mine has not been in production since about 1900. In the earlier operations, gold and some silver are reported to have been recovered from a drift that followed a quartz vein along a contact between biotite quartz monzonite and crystalline limestone. Elsewhere in the area north of Big Bear Lake, as on the slope at elevation 7450 east of the head of Furnace Canyon (SE $\frac{1}{4}$ sec. 24, T. 3 N., R. 1 W.), gold is associated with hematite in a quartz breccia where biotite quartz monzonite or granite porphyry intrude marble of the Furnace formation. Only a few of the gold claims are located directly at tactite or skarn deposits.

Placer Gold

The Holcomb Valley placer gold deposits were extensively worked for a few years following their dis-

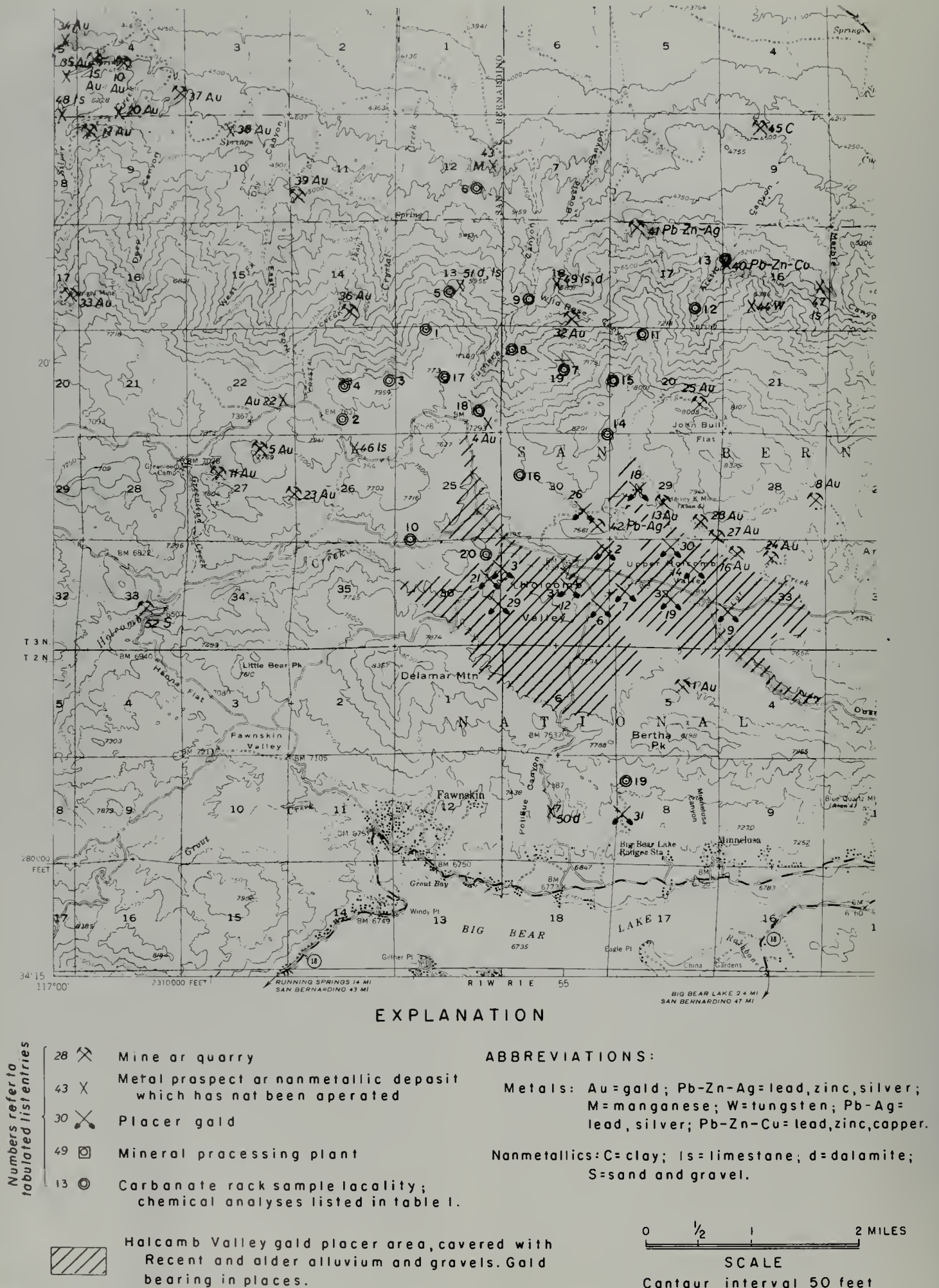


Figure 61. Economic map of San Bernardino Mountains north of Big Bear Lake.

covery in 1860 and this probably was the first large mining operation in San Bernardino County. The area is said to have been first worked by Mexicans who screened the soil for small lumps of gold-bearing hematite. The last reported productive placer mining was during the period 1933-41 when Mr. George Knudsen and Mr. William G. Lacy (Holcomb Valley Placer Company) operated the Holcomb and Garvey Placers in Upper Holcomb Valley (figs. 63, 64). Initial operations were by small scale hand methods, but in 1935 a four-bowl washing plant (fig. 69) was installed and mining was done with a small power shovel and two dump trucks. Beginning about 1938 the mining was done by Caterpillar tractor and carryall until operations ceased in 1941. Mr. Knudsen reports (personal communication May 1958) that the placer deposit was shallow, as thin as one foot deep in places. He estimates that 200,000 cubic yards of placer material were handled, yielding an average gold value of about 38 cents per yard.

The gold-bearing material mined in the central part of Holcomb Valley (fig. 63) is Recent alluvium and gravel and the material along the margins of Holcomb Valley and occupying most of Upper Holcomb Valley is older alluvium and gravels. Locally the gold-bearing gravels are termed "bench gravels" (figs. 65, 66, 67). These are included in the older alluvium and gravels shown on the accompanying geologic map (pl. 1). The older alluvium consists principally of deeply weathered massive quartzite and granitic rocks and small quantities of marble in a matrix of sand and gravel. The largest fragments rarely exceed 8 inches in diameter. Little is known of the depth of the older alluvium, but a water well completed in 1952 in the SE $\frac{1}{4}$ sec. 31, T. 3 N., R. 1 E. is said to have penetrated 100 feet of gravel and an additional 200 feet of interlayered clay and gravel without striking bedrock. The Recent alluvium and gravels is largely derived from the older alluvium, but lacks the reddish yellow color that characterizes the older alluvium.



Figure 62. Idle Harvey K mine, east side of Upper Halcamb Valley, 1956. This shaft, inclined about 45°, explores a mineralized fracture zone in biotite quartz monzonite.



Figure 63. Panarama of Upper Halcamb Valley gold placer area, east part of the Slap Jack claim. Camera facing south; February 1940. Tailing pile, left middleground, at Plant No. 1 of Halcamb Valley Placer Company. Ditch, in foreground, for water development, is in Recent alluvium and gravels locally termed "meadow ground". The gold-bearing gravels that were mined, included in the older alluvium and gravels shown on plate 1 and locally termed "bench gravels", occupy the gently rolling topography in the background, commencing at about the tree line. Photo courtesy Lacy Oil and Coal Company, Los Angeles, California.



Figure 64. Garvey placer, Upper Holcomb Valley. Camera facing south; February 1940. Tailing pond in foreground from Plant No. 2, Holcomb Valley Placer Company. Van Dusen Canyon in middle distance. Material in foreground and beyond tailing pile is locally termed "meadow" or "marsh ground". It is included in Recent alluvium and gravels on the accompanying geologic map, plate 1. Photo courtesy Lacy Oil Tool Company, Los Angeles, California.

Source of Holcomb Valley Placer Deposits. Water-worn pebbles were supplied by Mr. Earl Lee as typical of the richest source of gold-bearing ore from a placer deposit operated in Upper Holcomb Valley. Thin sections made from the pebbles show hematite cut by quartz veinlets. As the iron is secondary its origin is uncertain; it could have formed originally as a skarn or it may have been altered from a sulfide. Nearby primary deposits are localized in thinly mineralized fracture zones in biotite quartz monzonite (Harvey K, Ozier, and Osborne mines). The placer gold in Holcomb Valley appears to have accumulated by residual weathering and eluvial concentration from nearby primary deposits of probable hydrothermal origin and Upper Cenozoic age.

Iron

Hematite (specularite) occurs in a pod-shaped skarn deposit which has surface dimensions of 10 feet wide and about 50 feet long (fig. 18) at the Desert View mine (no. 5, fig. 61). The mine is described as a gold claim. Smaller lenses of hematite are associated with garnet and epidote in the vicinity.

Lead-Zinc-Silver

Lead, zinc and silver have been claimed in Van Dusen Canyon and north of Arrastre Flat, but have never been

seriously mined. The Silver Tip mine, described in the tabulated list, is reported to have shipped in 1937 an undetermined amount of ore containing 21.43 percent lead and 20.50 ounces of silver per ton.

Manganese

Pyrolusite occurs as thin coatings in nearly vertical fractures in white calcite and dolomite marble of the Furnace formation at the Echo mine (no. 43, fig. 61).

Tungsten

Scheelite is sparsely disseminated in tectite deposits at intrusive contacts between calcite and dolomite marble of the Furnace formation and biotite quartz monzonite or granite porphyry. The scheelite is associated with garnet, diopside, tremolite, wollastonite, and idocrase. At one locality, on the ridge east of Arctic Canyon, the presence in a scheelite-tremolite-idocrase-garnet tectite of about 1 percent scheelite is indicated by the ultraviolet lamp. None of the tungsten prospects is known to have been productive and none was in operation during 1958.

Age of Mineralization

Structural relations of rock units in the area and temperature stability fields of minerals associated with metals are guides to the age of mineralization.



Figure 65 (above). Typical occurrence of the gold-bearing "bench gravel" in Upper Halcamb Valley, west side of the Halcamb placer, February 1940. The cut bank was made by small power shovel during mining operations of the Halcamb Valley Placer Company. Beyond the cut is the tree-covered hummocky surface of the dumps left by the early-day operators, probably dating from the 1870s. Operations of the Halcamb Valley Placer Company during 1933-41 were confined to reworking these materials. Photo courtesy Lacy Oil Tool Company, Los Angeles, California.

Figure 67 (above). Gold-bearing "bench gravel" in Upper Halcamb Valley, central part of the Slap Jack placer, February 1940. The gravel mined here by small power shovel, was only 2 feet thick and underlain by practically barren material locally called "clay gravel". Part of the area mined by the Halcamb Valley Placer Company, 1933-41. Photo courtesy Lacy Oil Tool Company, Los Angeles, California.

Figure 66 (below). Gold-bearing "bench gravel" in Upper Halcamb Valley, February 1940. The gravel mined here by the Halcamb Valley Placer Company in the period 1933-41 ranged in thickness from 18 inches to 2 feet. Note the density of trees, which was one of the causes of high mining costs in the area. Photo courtesy Lacy Oil Tool Company, Los Angeles, California.

Figure 68 (below). Plant No. 2 operation site of the Halcamb Valley Placer Company in Upper Halcamb Valley, February 1940. Plant site at left center. Scraper-scarred ground in foreground was mined by Caterpillar tractor and carryall. This mining method was possible here because of the lack of trees and is said to have proved an efficient method of operation. The elevator and head frame at right are from earlier operators. Photo courtesy Lacy Oil Tool Company, Los Angeles, California.



Upper Mesozoic Deposits. Tactites and skarns that resulted from the intrusion of plutonic rocks in carbonate rocks of the Furnace formation are of Upper Mesozoic age. At these contacts hematite (specularite) and scheelite occur with garnet, tremolite, and other high-temperature minerals.

Upper Cenozoic Deposits. Sulfide mineralization of hydrothermal origin in granite cataclasite is at least in part of post-faulting (Upper Cenozoic) age (fig. 42). The introduction of gold ore along fault contacts between carbonate and granitic rocks and in shear and fracture zones in quartz monzonite probably occurred at the same time.

Nonmetallic Minerals

Clay

Mudstone lenses in the Tertiary Old Woman sandstone have been mined since mid-1957 to furnish part of the "clay" used as a source of alumina, silica, and iron in the manufacture of portland cement at the Cushenbury plant (fig. 72) of the Permanente Cement Company. Lenticular conglomerates, coarse sandstones and less abundant mudstones of the Old Woman sandstone formation crop out west of Arctic Canyon over an area about a quarter of a mile square. Mudstone lenses, especially those containing quartzite pebbles and cobbles, are sought out and mined from open pits. (A description of the Old Woman sandstone is on pages 45-46.)

Carbonate Rocks

About 15 square miles of the area mapped in this report is underlain by the Furnace formation (figs. 9, 10, 60) which consists chiefly of marble roof pendants intruded and isolated by plutonic rocks. The Furnace formation also contains thin lenses of micaceous siltstone and massive quartzite. Chemical analyses of the carbonate rocks show a marked gradation from nearly pure limestone or calcite marble to nearly pure dolomite or dolomite marble (table 1). This gradation was produced, as described earlier in this report, by dolomitization of post-Mississippian and pre-batholith age. Silica is a common impurity in the carbonate rocks.



Figure 69 (left). Na. 1 plant, Halcamb Valley Placer Campony, showing typical processing installation, February 1940. The gold-bearing material was fed through the trammel where it was washed and separated. Oversize from screen was carried up waste belt at left. Material passing through the screen was processed in the battery of Knudsen Bawls below. It appears that the concentrate from the Knudsen Bawls went to sluice boxes, where gold commonly is caught by mercury on riffles. Photo courtesy Lacy Oil Tool Company, Los Angeles, California.

Figure 70 (above). Placer tailings surround abandoned cabin in Upper Halcamb Valley, 1956.

Figure 71 (below). Cushenbury limestone quarry of Permanente Cement Company, 1957. Electric-powered 5-cubic-yard shovel loading 18-cubic-yard end dump quarry truck which transports the limestone to the primary crusher. Approximately 1,000,000 tons of limestone are quarried each year for use in the manufacture of portland cement. Photo courtesy Permanente Cement Company, Oakland, California.





Figure 72. View northwest from quarry toward Cushenbury plant of Permanente Cement Company, 1957. In foreground are portions of crushing and stockpiling facilities which handle limestone obtained from adjacent quarry. The limestone is moved via belt conveyor to manufacturing plant in middleground. Lucerne Valley in background. Photo courtesy Permanente Cement Company, Oakland, California.

Dolomite. White and gray dolomites of the Furnace formation are broadly distributed over the mapped area. Samples collected at random, but believed typical of large rock units (table 1), suggest that large deposits of high-grade dolomite may exist on the north flank of the San Bernardino Mountains, especially between Arctic and Crystal Creek Canyons. Several deposits in the vicinity of Furnace Canyon were actively explored during 1958, but by July there had been no production.

Limestone. Crystalline limestone deposits of commercial quality currently are potentially the most valuable mineral resource in the area. They occur in the Furnace formation. The deposits are widely distributed in the mapped area and extend both east and west out of the area. Reserves of rock are immense but insufficient sample data (table 1) are available to establish the extent of the high-calcium rock. The largest, most uniform deposits of white high-calcium rock probably occur in the vicinity of Furnace Canyon.

High-calcium limestone deposits within the mapped area had not been mined by July 1958. Similar deposits, however, about 1 mile to the east along Cushenbury Canyon were mined on a large scale during 1958 (fig. 71).

These deposits furnish the limestone for the manufacture of portland cement at the Cushenbury plant of the Permanente Cement Company. This two-kiln wet-process plant (fig. 72) had a rated annual capacity of over $2\frac{1}{2}$ million barrels when placed in operation in April 1957. The Cushenbury quarries also furnish a large tonnage of flux stone for use by the Kaiser Steel Corporation at Fontana.

Silica. Relatively pure quartzites of the Chicopee Canyon formation are exposed northeast of Fawnskin, particularly on the ridge east of Delamar Mountain (fig. 6). The massive white quartzite is of potential value for use in the manufacture of portland cement, as an abrasive, and for refractory material.

REFERENCES CITED

- Bowen, N. L., 1940, Progressive metamorphism of siliceous limestone and dolomite: Jour. Geology, vol. 48, pp. 225-274.
- Bowen, O. E. Jr., 1954, Geology and mineral deposits of Barstow quadrangle, San Bernardino County, California: California Div. Mines Bull. 165, 185 pp.
- Buddington, A. F., 1948, Origin of granitic rocks of

- the northwest Adirondacks, in *Origin of granite*: Geol. Soc. America Mem. 28, pp. 21-43.
- Clondman, H. E., Huguenin, E., and Merrill, F. J. H., 1919, San Bernardino County: California Min. Bur. Rept. 15, pp. 798-799.
- Crawford, J. J., 1894, Mines and mining products of California: California Min. Bur. Rept. 12, pp. 233-235.
- Crawford, J. J., 1896, Gold—San Bernardino County: California Min. Bur. Rept. 13, pp. 322-323.
- DeGroot, H., 1890, San Bernardino County—its mountains, plains, and valleys: California Min. Bur. Rept. 10, p. 523.
- Dibblee, T. W. Jr., 1948, Tertiary stratigraphic units of western Mojave Desert, California: Am. Assoc. Petroleum Geologists Bull., vol. 42, no. 1, pp. 135-144.
- Eric, J. H., 1948, Tabulation of copper properties of California: California Div. Mines Bull. 144, p. 312.
- Eskola, P., 1920, The mineral facies of rocks: Norsk geol. tidsskr., vol. 6, pp. 143-194.
- Goldschmidt, V. M., 1911, Die Kontaktmetamorphose im Kristianiagebiet: Vidensk. Skr., I, Mat.-Naturv. Kl., no. 11.
- Goodspeed, G. E., 1947, Xenoliths and skialiths (abst.): Geol. Soc. America Bull., vol. 48, p. 1251.
- Goodspeed, G. E., 1948, Origin of granites, in *Origin of granite*: Geol. Soc. America Mem. 28, pp. 55-79.
- Goodwin, J. G., 1957, Lead and zinc in California: California Jour. Mines and Geology, vol. 53, p. 670.
- Grout, F. F., 1948, Origin of granite, in *Origin of granite*: Geol. Soc. America Mem. 28, pp. 45-55.
- Guillou, R. B., 1953, Geology of the Johnston Grade area, San Bernardino County, California: California Div. Mines Special Rept. 31, 18 pp.
- Haley, C. S., 1923, Gold placers of California: California Min. Bur. Bull. 92, p. 154.
- Harker, Alfred, 1904, The Tertiary igneous rocks of Skye: Great Britain Geol. Survey Mem., p. 144-151.
- Harker, Alfred, 1939, Metamorphism, 2d ed., New York, E. P. Dutton & Co., Inc.
- Hershey, O. H., 1902, Some Tertiary formations of southern California: Am. Geologist, vol. 29, p. 365.
- Hess, F. L., 1919, Taetite, the product of contact metamorphism: Am. Jour. Sci. 4th ser., vol. 48, pp. 377-378.
- Hewett, D. F., and Glass, J. J., 1953, Two uranium-bearing pegmatite bodies in San Bernardino County, California: Am. Mineralogist, vol. 38, pp. 1049-1051.
- Holcomb, W. F., 1900, Letter to the San Bernardino Society of Pioneers dated January 27, in Western Historical Association, 1922, History of San Bernardino and Riverside Counties.
- Kerr, P. F., 1946, Tungsten mineralization in the United States: Geol. Soc. America Mem. 15.
- Laizure, C. McK, Symons, H. H., and Sanborn, Frank, 1934, Elementary placer mining in California and notes on the milling of gold ores: California Div. Mines Rept. 30, p. 250.
- Larsen, E. S. Jr., Gottfried, David, Jaffe, H., and Waring, C. L., 1954, Age of the southern California, Sierra Nevada, and Idaho batholiths: Geol. Soc. America Bull., vol. 65, no. 12, pt. 2, December 1954, p. 1277.
- Miller, W. J., 1944, Geology of parts of the Barstow quadrangle, San Bernardino County, California: California Div. Mines Rept. 40, pp. 72-112.
- Noble, L. F., 1926, The San Andreas rift and some other active faults in the desert region of southeastern California: Carnegie Inst. Year Book No. 25, pp. 415-428.
- Richmond, J. F., 1957, Independence #1 mine, Holcomb Mining District, San Bernardino Mountains, unpublished private report, 4 pp.
- Richmond, James Frank, 1954, Petrology and structure of the San Bernardino Mountains north of Big Bear Lake, California: unpub. Ph.D. thesis, School of Mineral Sciences, Stanford University.
- Rodgers, John, 1940, Distinction between calcite and dolomite on polished surfaces: Am. Jour. Sci., vol. 238, no. 11, pp. 788-798.
- Sampson, R. J., 1932, Placers of southern California: California Div. Mines Rept. 28, p. 254.
- Sederholm, J. J., 1926, On migmatites and associated pre-Cambrian rocks of southwestern Finland, Part 2: Bull. Comm. Geol. de Finlande No. 77.
- Shand, S. J., 1942, Phase petrology in the Cortlandt complex, New York: Geol. Soc. America Bull., vol. 53, pp. 409-428.
- Shreve, R. L., 1958, Geology and mechanics of the Blackhawk landslide: unpub. Ph.D. thesis on open file, California Institute of Technology, Pasadena, Calif.
- Stock, Chester, and Furlong, E. L., 1926, New canid and rhinocerotid remains from the Ricardo Pliocene of the Mohave Desert, California: Univ. California, Dept. Geol. Sci. Bull., vol. 16, pp. 43-60.
- Teall, J. J. H., 1903, On dedolomitization: Geol. Mag., new ser., vol. 10, pp. 513-514.
- Tilley, C. E., 1948, Earlier stages in the metamorphism of siliceous dolomites: Mineralog. Mag., vol. 28, pp. 272-276.
- Tilley, C. E., 1951, A note on the progressive metamorphism of siliceous limestones and dolomites: Geol. Mag., vol. 88, pp. 175-178.
- Tucker, W. B., 1921, Los Angeles field division [San Bernardino County]: California Min. Bur. Rept. 17, p. 349.
- Tucker, W. B., and Sampson, R. J., 1930, Los Angeles field division [San Bernardino County]: California Div. Mines Rept. 26, pp. 241, 245.
- Tucker, W. B., and Sampson, R. J., 1931, Los Angeles field division [San Bernardino County]: California Div. Mines Rept. 27, pp. 301, 305-306.
- Turner, F. J., 1948, Mineralogical and structural evolution of the metamorphic rocks: Geol. Soc. America Mem. 30.
- Tuttle, O. F., 1952, Origin of the contrasting mineralogy of the extrusive and plutonic salic rocks: Jour. Geology, vol. 60, pp. 107-124.
- Vaughan, F. E., 1922, Geology of San Bernardino Mountains north of San Geronimo Pass: Univ. California, Dept. Geol. Sci. Bull., vol. 13, pp. 319-411.
- Wickman, F. E., 1944, A graph for the calculation of minerals according to the lead method: Sveriges geol. undersokning, Arsbok 37 (1943), N:07.
- Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U.S. Geol. Survey Bull. 896.
- Woodford, A. O., and Harriss, T. F., 1928, Geology of Blackhawk Canyon, San Bernardino Mountains, California: Univ. California, Dept. Geol. Sci. Bull., vol. 17, pp. 265-304.
- Wright, L. A., Stewart, R. M., Gay, T. E. Jr., and Hazenbush, G. C., 1953, Mines and mineral deposits of San Bernardino County, California: California Jour. Mines and Geology, vol. 49, nos. 1 and 2.

**TABULATED LIST OF MINES AND MINERAL DEPOSITS IN AN AREA
OF THE SAN BERNARDINO MOUNTAINS NORTH OF BIG BEAR
LAKE, SAN BERNARDINO COUNTY, CALIFORNIA**

BY CLIFFTON H. GRAY, JR.

The data contained in the following tabulated list were drawn from investigations by the writer as well as from other sources, both published and unpublished, believed by the writer to be authentic. Field notes supplied by Dr. J. F. Richmond assisted materially in the preparation of many descriptions. All properties listed, except several listed in the column headed "location" as "not verified," were visited by the writer during 1956-58, or by Dr. Richmond during 1952-58. In addition to the properties listed, unidentified prospects exist.

The list is arranged in alphabetical order by mineral commodity. The number in the first column is the number given the location of the deposit on the map, figure 61. Synonyms are given in parentheses after the preferred name and appear as cross references elsewhere in the list.

The date of ownership follows the owner's name and address. Many of the ownership data were obtained from the office of the San Bernardino County Assessor and the U.S. Forest Service. Ownership data are believed to be accurate as of the time the report was written, but the data commonly were not completely verified. Locations in miles from reference points are approximate airline distances.

References appear in parentheses in the last column and refer to the accompanying bibliography. Only the last names of the authors are given. The first number after each name is the year of publication, and is separated from the page reference by a colon. Page numbers followed by "t" indicate reference to a tabulated list. Succeeding references are preceded by semicolons.

GOLD

Map no.	Name of claim, mine, or group	Location	Owner (name, address)	Geology	Remarks and references
	Artie Canyon	Sec. 31, T. 3 N., R. 1 E., S.B.M., in Holcomb Valley. Not verified, 1958.	W. B. Calhoun, Box 61, Fawnskin, 1958.	Not determined.	Unpatented claim, from records of San Bernardino County Assessor.
	Artie Canyon	Sec. 32, T. 3 N., R. 1 E., S.B.M., in Holcomb Valley. Not verified, 1958.	Maymie Basey, 1954 Budlong Avenue, Los Angeles 7, 1958.	Not determined.	Unpatented claim, from records of San Bernardino County Assessor.
1	Bertha Peak	NE $\frac{1}{4}$ sec. 5, T. 2 N., R. 1 E., S.B.M., on the northeast flank of Bertha Peak, 1- $\frac{3}{4}$ miles north of Big Bear Lake Ranger Station.	A. A. Fairchild, Box 932, Los Angeles 53, 1958.	Area of contact between quartzite of Chicopee Canyon formation and granite porphyry.	Developed by two 60-foot adits and three adits of unknown length, now caved. Owner reports old adit uncovered by bulldozer work in 1958 and copper ore zone found in face of adit. Probably a gold prospect dating from the 1890s. No known production.
2	Bucyrus and Triangle Placers	NE $\frac{1}{4}$ sec. 31, NW $\frac{1}{4}$ sec. 32, T. 3 N., R. 1 E., S.B.M., along the northwest margin of Upper Holcomb Valley, 3 $\frac{1}{2}$ miles northeast of Fawnskin.	Kern Rock Company, c/o Alta Vista and Kentucky St., Bakersfield, 1958.	Biotite quartz monzonite contains several small pendants of Furnace formation calcite and dolomite marble. South part of property covered by the placer deposit of Recent alluvium.	Two patented placer claims (Bucyrus and Triangle) total 32.206 acres.
3	Chiquita Placer	Sec. 31, T. 3 N., R. 1 E., S.B.M., in Holcomb Valley. Not verified, 1958.	J. C. Martin and R. W. Hitchcock et al., 1363 E Street, San Bernardino, 1958.	Area covered by Recent alluvium and older alluvium and gravels.	Part of the Holcomb Valley gold placer area. This claim (6.06 acres) apparently was originally part of the Mohave Gravel mine or Valley Consolidated group, patented in the 1890s. Idle 1958.
4	Courtland	SE $\frac{1}{4}$ sec. 24, T. 3 N., R. 1 W., S.B.M., SW $\frac{1}{4}$ sec. 19, T. 3 N., R. 1 E., S.B.M., at the head of Furnace Canyon, 4 miles northeast of Fawnskin.	Frank B. Herbert, 114 Hackett Pl., Los Angeles 42 (1957).	Furnace formation calcite and dolomite marble intruded by granite porphyry dike. Owner reports hematite and gold occur in the limestone in a northwest-trending vein.	Four lode claims located 1955 (Courtland 1-4). Prospected by shallow pits. Idle 1958.
5	Desert View	NE $\frac{1}{4}$ sec. 27, T. 3 N., R. 1 W., S.B.M., 4 miles northwest of Fawnskin.	A. P. Outley, P.O. Box 252, Etiwanda, 1958.	Pod-shaped contact deposit of skarn consisting of massive specular hematite and coarse epidote, with surface dimensions of about 10 by 50 feet, occurs in Furnace formation calcite and dolomite marble. Near intrusive contact of biotite quartz monzonite. The hematite-rich part of the skarn zone is irregular, ranging from 1 foot to 30 inches in width, and steeply dipping. It can be traced northwest of the mine area for about 200 yards N. 10° W. across the Greenlead road.	Crosscut adit 30 feet long driven east to intersect the skarn zone. Several thin hematite-rich skarn stringers were cut, but may not be the main mass exposed on the hill above. Idle 1958.
6	Eagle Placer	Sec. 31, T. 3 N., R. 1 E., S.B.M., in Holcomb Valley. Not verified, 1958.	Jeane Clair Rogers, Box 260, Big Bear Lake, 1958.	Area covered by Recent alluvium and older alluvium and gravels. Older alluvium consists chiefly of weathered granitic rocks in a matrix of sand and gravel.	Part of the Holcomb Valley gold placer area. This claim apparently was originally part of the Mohave Gravel mine or Valley Consolidated group. Patented in the 1890s. Idle 1958.
7	Eagle, Croesus, Hope, Last Chance, et al. Placer	Secs. 31, 32, T. 3 N., R. 1 E., S.B.M., in Holcomb Valley and Upper Holcomb Valley. Not verified, 1958.	Kern Rock Company, c/o Alta Vista and Kentucky St., Bakersfield, 1958.	Area covered by older alluvium and gravels and Recent alluvium.	Part of the Holcomb Valley gold placer area. These claims, which include 143.88 acres, apparently were originally part of the Mohave Gravel mine or Valley Consolidated group, patented in the 1890s. Idle 1958.
8	Edgworth No. 1	NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 28, T. 3 N., R. 1 E., S.B.M., northwest of Arrastre Flat, 4 miles northwest of Big Bear City.	Frank M. Reeves, P.O. Box 4, Big Bear City, 1958.	Fine-grained altered biotite quartz monzonite body about 300 feet wide trends N. 50° W., a fine-grained facies of coarser-grained enclosing rock.	Shaft about 40 feet deep explores the fine-grained biotite quartz monzonite. Idle 1958.
9	Garvey Placer	Secs. 32, 33, T. 3 N., R. 1 E., S.B.M., sec. 4, T. 2 N., R. 1 E., S.B.M., along Caribou Creek in east Upper Holcomb Valley and the northwest part of Van Dusen Canyon.	William G. Lacy c/o Lacy Oil Tool Co., 973 N. Main St., Los Angeles 12, 1958.	Area covered by older alluvium and gravels and Recent alluvium.	Holcomb Valley gold placer area. One patented claim 143 acres. Part of the first area worked in Holcomb Valley, patented to Richard Garvey in 1873. Unsuccessfully developed by Holcomb Valley Co., Ltd. in late 1880s to 1894. Part of the Holcomb Valley Placer Co. operation 1933-41. Idle 1958.

GOLD—Continued

Map no.	Name of claim, mine, or group	Location	Owner (name, address)	Geology	Remarks and references
10	Gold Button (Henshaw, Murray)	S½ sec. 4, T. 3 N., R. 1 W., S.B.M., 5¼ miles southwest of Lucerne Valley. North face of San Bernardino Mts., west side of Silver Creek.	Bill Weldon, Box 446, Lucerne Valley, 1958.	Shear zone in granite cataclasite. Strike N. 80° W., dip 70° SW., width 2 to 6 ft. Narrow clay gouge zone is reported to have carried gold values with some lead, silver, and copper. Rock on main dump (1958) included biotite quartz diorite, gneiss and quartzite with minor iron, manganese and copper stains. Lower adit about 100 feet long trends south. First 50 ft. in Quaternary breccia-conglomerate with many boulders of granitic rock. Breccia-conglomerate is in fault contact with granite cataclasite, contact is vertical, strikes east, dips 70° S. Upper adit, 75 ft. above and 200 ft. south of lower adit, driven N. 10° E. First 30 ft. in breccia-conglomerate; at 40 ft. shear zone strikes N. 60° E., dips 40° S.; at 50 ft. shear strikes east and is vertical; at 75 ft. shear strikes east and dips 40° S. Walls also show minor fractures. Adit caved at 100 ft.	By 1930 developed by 300-ft. crosscut adit driven S. 10° E., with east and west drifts from near the face of crosscut, each about 15 ft.; from base of east drift a 100-ft. raise to surface. Several short adits driven long before 1930 apparently did not encounter vein material. Production undetermined. Idle 1958. (Eric 48:312; Tucker 30:245; 31:305-306).
11	Green Lead	SE¼ sec. 28, SW¼ sec. 27, T. 3 N., R. 1 W., S.B.M., 3½ miles northwest of Fawnskin.	Glenn I. Campbell, 14332 Dickens St., Sherman Oaks, 1958.	Gold- and silver-bearing, copper-stained quartz vein along a contact between biotite quartz monzonite and crystalline limestone (Furnace formation). Vein 2-4 ft. wide, strikes northwest, dips southeast. Reported to contain free milling gold with some sulfide ore. South wall of drift from Garvey adit is reported by owner (July 1953) to contain streaks of a green mineral analyzed as silver bromide.	One claim and millsite (15.28 acres) patented 1876. Reported to have been worked intermittently 1894-98; mined from 400-ft. shaft with level workings at 50 ft., 100 ft., 200 ft., 300 ft., and 400 ft. Garvey adit 300 ft. long in 1919. Old Garvey adit reopened and cleaned out to a length of 370 feet in 1953, but no ore body found, adit driven S. 44° E., for 370 feet, then drifted S. 45° W. for 40 feet. Shaft not found in 1953. Idle 1958. (Crawford 96:322; Wright and others 53:41t.).
12	Greenwood Placer	Sec. 31, T. 3 N., R. 1 E., S.B.M., in Holcomb Valley. Not verified, 1958.	R. W. Hitchcock et al., 762 Lynwood, San Bernardino, 1958.	Area covered mostly by Recent alluvium, but some older alluvium and gravels.	Part of the Holcomb Valley gold placer area. This claim (117.47 acres) apparently was originally part of the Mohave Gravel mine or Valley Consolidated group, patented in the 1890s. Idle 1958.
13	Harvey K (Hepburn)	Sec. 29, T. 3 N., R. 1 E., S.B.M., at the north margin of Upper Holcomb Valley, 4 miles northeast of Fawnskin.	Undetermined, 1958. Lt. Col. James M. Smith (1956); M. E. and A. K. Hepburn, Box 5, Fawnskin (1953).	Gold-bearing, locally siliceous fracture zone in biotite quartz monzonite.	Main working is shaft inclined about 45° which appears to parallel a 4-in.-to 6-in.-wide quartz vein that is weakly mineralized. Earl Lee reports (oral communication August 1953) that the shaft is 90 ft. deep, and then drifted 75-80 ft. east, and that gold was found in 8- to 10-in. "sulphide" veins which were discontinuous. Other local residents report the inclined shaft to be 200 ft. deep with short drifts. Probably opened in 1890s. Small tonnage gold ore shipped. Idle 1958. (Wright and others 53:41t.).
	Henshaw				See Gold Button.
	Hepburn				See Harvey K.
	H.O.K.	Sec. 32, T. 3 N., R. 1 E., S.B.M., in Holcomb Valley. Not verified, 1958.	Albert M. Haynes, Box 97, Fawnskin, 1958.	Not determined.	Unpatented claim from records of San Bernardino County Assessor.
	Holcomb	Sec. 32, T. 3 N., R. 1 E., S.B.M., in Upper Holcomb Valley. Not verified, 1958.	Ora R. Willeford, 1958.	Area covered mostly by older alluvium and gravels, and some Recent alluvium.	Part of the Holcomb Valley gold placer area. Probably part of the Holcomb placer claim in NE¼ sec. 32. Records show this area was surveyed for patent in 1873. Idle 1958.
14	Holcomb Placer	Secs. 29, 32, 33, T. 3 N., R. 1 E., S.B.M., center of Upper Holcomb Valley, 3 miles north of Big Bear Lake Ranger Station.	William G. Lacy, c/o Lacy Oil Tool Co., 973 N. Main St., Los Angeles 12, 1958.	Area covered by older alluvium and gravels and Recent alluvium.	Holcomb Valley gold placer area. One patented claim 110.57 acres. Part of the first area worked in Holcomb Valley and originally surveyed for patent in 1873. Unsuccessfully developed by Holcomb Valley Co., Ltd. in late 1880s to 1894. Included in the Holcomb Valley Placer Co. operation 1933-41. Idle 1958.

GOLD—Continued

Map no.	Name of claim, mine, or group	Location	Owner (name, address)	Geology	Remarks and references
	Holcomb Valley Placers	Secs. 29, 31, 32, 33, T. 3 N., R. 1 E., S.B.M.; sec. 36, T. 3 N., R. 1 W., S.B.M.; secs. 4, 5, 6, T. 2 N., R. 1 E., S.B.M.; 3 miles north of Big Bear Lake.	Numerous holdings. See <i>herein</i> Holcomb Placer, Garvey Placer, Mountain Bear Consolidated, Slap Jack, Lucky Bill, Mohave Gravel mine, Reservoir, Valley Consolidated group, Eagle, Chiquita, Greenwood.	Area covered by older alluvium and gravels and Recent alluvium. The older alluvium, locally known as "bench gravels" is gold-bearing. The gold apparently is contained in hematite-quartz pebbles. Early day operators reported the gold-bearing gravel to be 10 to 25 ft. thick and in some places as much as 60 ft. thick. Pay gravel was reported by the early day operators to contain from \$.25 to \$.50 in gold per cu. yd.	Placer discovered 1860; extensively and profitably worked for a few years; intermittently worked since. Probably first large mining operation in San Bernardino County. Unsuccessfully developed by Holcomb Valley Co., Ltd., an English concern, in late 1880s to 1894. Last worked 1933-41 by Holcomb Valley Placer Co., which see <i>herein</i> . Sparsity of water a hindrance. Idle 1958. (Cloudman 19:798-799; Crawford 94:233-235; 96:323; De Groot 94:523; Haley 23:154; Laizure 34:250; Tucker 20:349; 30:241; 31:301; Wright and others 53:42-43t.)
	Holcomb Valley Placer Company	Secs. 29, 32, 33, T. 3 N., R. 1 E., S.B.M.; sec. 4, T. 2 N., R. 1 E., S.B.M., in Upper Holcomb Valley, 3 miles north of Big Bear Lake.	William G. Lacy, c/o Lacy Oil Tool Co., 973 N. Main St., Los Angeles, 12, 1958.	Area covered by older alluvium and gravels and Recent alluvium. The older alluvium, locally known as "bench gravels" is gold-bearing. The gold apparently is contained in hematite-quartz pebbles.	During 1933-41 the Holcomb Valley Placer Co. reworked gravels which had been previously worked by a number of operators, mostly in the period 1860-94. Initial operations from 1933-35 were by small-scale hand methods by George Knudsen; in 1935 a four-bowl washing plant was installed; in 1936 Mr. Knudsen joined W. G. Lacy in partnership and mining was done with a small power shovel and two dump trucks; beginning about 1938 mining was done by caterpillar tractor and carry-all, the method used until operations ceased about 1941. Seven plant installations were operated. The gold-bearing re-worked gravels are reported to have ranged from 1 to 6 ft. in thickness but to have averaged about 2 ft. thick over most of the area. It is reported that from \$1.00 to less than \$0.20 per ton in gold was recovered from the reworked gravels (private report, Lacy Oil Tool Co.). Mr. Knudsen estimates that 200,000 cu. yds. of placer material were handled, yielding an average gold value of about 38 cents per yard. (Personal communication, George Knudsen, May 1958.) Area worked included the Garvey, Holcomb, Lucky Bill, and Slap Jack placer claims, which see <i>herein</i> . Idle 1958.
15	Holdcomb	N $\frac{1}{2}$ SW $\frac{1}{4}$ sec. 4, T. 3 N., R. 1 W., S.B.M., in the north foothills of the San Bernardino Mountains, $\frac{1}{2}$ mile west of Silver Creek.	Undetermined, 1958; Holdcomb brothers, Lucerne Valley, (1953).	Two faults in granite cataclasite. Thin shears 2 in. wide strike N. 30° E., dip 45° S., and extend across principal adit.	Several short adits and one adit about 150 ft. long driven southeast. Idle 1958.
16	Independence mine no. 1	N $\frac{1}{2}$ sec. 33, T. 3 N., R. 1 E., S.B.M., near the boundary of sec. 28, at the north edge of Upper Holcomb Valley, 3 miles northeast of Big Bear Lake Ranger Station.	T. R. Tousley and Robert Read, 2200 South Genesee Avenue, Los Angeles 16, 1958.	The country rock in the mine area is biotite quartz monzonite with coarse granitic texture. Quartz veins, which trend northwest, cut the quartz monzonite. The most extensively explored quartz vein strikes N. 60° W., and dips 70°-75° SW. The vein ranges from 3 to 12 in. in width, with an apparent average width of 6 in. It can be traced on the surface northwest from the mine portal about 100 ft., where the vein frays into smaller veins that bend in a more northerly direction. Slickensides and thin gouge zones in the vein walls exposed in the workings indicate that the quartz vein occupies a fault. Abundant pyrite and traces of chalcopyrite form thin coatings in recemented fractures in the quartz vein. The owner reports the best assays were obtained as free-milling gold from vuggy portions of the vein where the quartz is stained by limonite.	Discovered about 1955. By May 1957, explored by a 75-ft. adit that follows the footwall of a quartz vein that strikes N. 60° W. Adit averages 5 ft. in width and is from 6 to 8 ft. high. About 15 ft. in from the portal a 6- by 5-ft. shaft has been sunk along the footwall of the quartz vein to a depth of 15 ft. below the adit level. Mr. Tousley reports that three assays by E. Eisenhauer, Los Angeles, showed values of \$202, \$532, and \$350 per ton. The samples on which the assays were made are reported by the owners to have been obtained by channelling across the width of the quartz vein at depths of 1 ft., 10 ft., and 15 ft., respectively in the shaft sunk along the footwall. Ten tons of ore are reported to have been shipped by a lessee to the Burton mill at Rosamond in September 1955, but with unsatisfactory results. A $\frac{3}{4}$ -ton shipment to the Burton mill in the spring of 1956 is reported to have indicated a value of \$90.75 per ton. Development was continuing during 1958. (Richmond 57:4 pp.)

GOLD—Continued

Map no.	Name of claim, mine, or group	Location	Owner (name, address)	Geology	Remarks and references
17	J.A.W.	NW¼ sec. 9, T. 3 N., R. 1 W., S.B.M., along the east side of Silver Creek, 6 miles southwest of Lucerne Valley.	H. Johnny, D. Allen, W. W. Woods, 1958.	Sheared zones in migmatites of biotite quartz monzonite.	Principal shears trend northwest and are stained red-brown and yellow-brown with iron oxide, but no indication of vein material or ore. Explored by three principal adits driven southwest from N. 30° E. to N. 40° E., and one vertical shaft. Adits apparently 50 to 200 ft. long, caved at portals. Idle 1958.
18	Lee Placers	W½ sec. 29, T. 3 N., R. 1 E., S.B.M., north edge of Upper Holcomb Valley, 4 miles north of Big Bear Lake Ranger Station.	Earl E. Lee, General Delivery, Fawnskin, 1958.	Valley covered with older alluvium and gravels surrounded by biotite quartz monzonite. Alluvium consists chiefly of cobbles of weathered massive quartzite and granitic rocks and less abundant marble in a matrix of sand and gravel. Thin sections made from water-worn pebbles supplied by Mr. Lee as typical of the richest source of gold-bearing ore show hematite cut by quartz veins.	Worked from numerous shallow surface cuts. Operated intermittently by the Lee family since 1916. Some production; total not known.
	Little Nugget	Secs. 31, 32, T. 3 N., R. 1 E., S.B.M., in Holcomb Valley and Upper Holcomb Valley. Not verified, 1958.	Carrie Coykendall, 15332 E. North St., Anaheim, 1958.	Not determined.	Patented claim, 19.64 acres, from records of San Bernardino County Assessor.
19	Lucky Bill	NW¼SE¼ sec. 32, T. 3 N., R. 1 E., S.B.M., along the south margin of Upper Holcomb Valley, 3 miles northeast of Fawnskin.	William G. Lacy c/o Lacy Oil Tool Co., 973 N. Main St., Los Angeles 12, 1958.	Area covered by older alluvium and gravels.	Holcomb Valley gold placer area. Part of the Holcomb Valley Placer Co. operation 1933-41. Developed by two shallow shafts. Idle 1958.
20	McLellan's	SW¼ sec. 4, T. 3 N., R. 1 W., S.B.M., bottom of Silver Creek, 5½ miles southwest of Lucerne Valley.	Undetermined, 1958; Bill McLellan (1953).	Area of contact between biotite quartz monzonite and migmatite.	No indication of ore. Idle 1958.
	Mohave Gravel mine	Secs. 31, 32, T. 3 N., R. 1 E., S.B.M., sec. 36, T. 3 N., R. 1 W., S.B.M., in Holcomb Valley and Upper Holcomb Valley.	See remarks.	Area covered by older alluvium and gravels, and Recent alluvium.	Holcomb Valley gold placer area. In 1890 included 5 claims totaling 339.80 acres, Bullion, Eagle, Greenwood, Last Chance, Vulture. Apparently, at least in part, the same area later known as the Valley Consolidated Group No. 1, which see herein. Included in the area unsuccessfully developed by Holcomb Valley Co., Ltd., in late 1880s to 1894. Idle 1958.
21	Mountain Bear Consolidated mine	NE¼ sec. 36, T. 3 N., R. 1 W., S.B.M., NW¼ sec. 31, T. 3 N., R. 1 E., S.B.M., in the west part of Holcomb Valley.	Undetermined, 1958.	Area covered by older alluvium and gravels, and Recent alluvium.	Holcomb Valley gold placer area. Two claims (Argos, Bear) totaling 197.73 acres were patented to the Mountain Bear Gold Mining Company in 1900. Idle, 1958.
	Murray				See Gold Button.
22	Nonaday	SE¼ sec. 22, T. 3 N., R. 1 W., S.B.M., 4½ miles northwest of Fawnskin. Not verified, 1958.	Undetermined, 1958; Earl E. Lee, General Delivery, Fawnskin (1956).	Area of contact between calcite and dolomite marble of the Furnace formation and granitic rocks (granite porphyry and biotite quartz monzonite).	Reported to be developed by two shallow pits. Idle 1958.
23	Old Pen	W¼ corner, sec. 26, T. 3 N., R. 1 W., S.B.M., 3½ miles northwest of Fawnskin.	Undetermined, 1958; Wm. F. Zempel (1952).	Massive recrystallized vein quartz in biotite quartz monzonite. Ore mineral (hematite?) fills fractures in ladder vein structure.	Developed by shaft 20 ft. deep with wood ladder in good condition. Idle 1958.
24	Osborne	NW¼NE¼ sec. 33, T. 3 N., R. 1 E., S.B.M., in northeast margin of Holcomb Valley, north of Caribou Creek.	Title to State (1957); W. A. Franklin estate, Los Angeles (1952).	Biotite quartz monzonite contains west-northwest-trending quartz veins. Most extensively worked vein is on middle (San Bernardino) claim; poorly exposed but reported to be at least 500 ft. long, to dip moderately to steeply northward, and to contain a 1- to 4-ft. width of gold-bearing quartz for most of its length. A second vein, as close as 100 ft. north of main shaft, worked for about 400 ft. along its strike, but to much shallower depth.	Three noncontiguous and en echelon lode claims, Mammoth, Olio, San Bernardino, total 8.74 acres, patented 1873. Worked for gold in the late 1800s, but idle for more than 50 years. San Bernardino vein developed by 240-ft. (?) shaft inclined about 40° N., partly caved and waterfilled. Most of the workings lie within 300 ft. east of shaft, beneath an area of dump material. West of shaft the workings are believed to be largely above the 60-ft. level and extend only a short distance beyond a holed-through raise about 150 ft. from main shaft. Long idle. (De Groot 90:523; Wright and others 53:77, 52t).

GOLD—Continued

Map no.	Name of claim, mine, or group	Location	Owner (name, address)	Geology	Remarks and references
	Ozier				See Ozier.
25	Ozier (Ozier)	SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 20, T. 3 N., R. 1 E., S.B.M., on John Bull Flat, 1 $\frac{1}{2}$ miles north of Upper Holcomb Valley.	Walter S. Alf, Box 36, Daggett, 1958. Two lode claims, Jesus Redondo and Ramona, total 26.02 acres, patented 1877 to Mrs. Anna Ozier.	Mine area underlain by hard to thoroughly decomposed biotite quartz monzonite. Workings followed a group of steeply southwest dipping, west-northwest trending fractures closely spaced through a zone 200 ft. wide. The gold-bearing rock reported to be free milling and highly hematitic, but to have contained little quartz vein material.	Mine opened by Mexicans, probably in the late 1850s. Reported to have been most active in the period 1860-90, but inactive for about 50 years. Probably contains the most extensive lode workings in Holcomb Valley area. Workings are caved and now shown only by much dump material. Development by numerous adits and shallow shafts, two principal shafts reported to have been 75 and 100 ft. deep, with level workings at base. Output unknown, but believed significant. Long idle. (Wright and others 53:77-78, 52t).
26	Pioneer Placer	SE $\frac{1}{4}$ sec. 30, T. 3 N., R. 1 E., S.B.M., north of Holcomb Valley, 3 $\frac{1}{2}$ miles northeast of Fawnskin.	Undetermined, 1958; W. B. Calhoun, Box 61, Fawnskin (1952).	Older alluvium fills wash and is surrounded by blue-gray, cherty calcite and dolomite marble of the Furnace formation.	
27	Pocilio	SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 28, SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 29, NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 32, N $\frac{1}{2}$ NW $\frac{1}{4}$ sec. 33, T. 3 N., R. 1 E., S.B.M., along the northeast margin of Upper Holcomb Valley, 3 miles north of Big Bear Lake Ranger Station.	Kern Rock Company, c/o Alta Vista and Kentucky St., Bakersfield, 1958.	Northwest-trending quartz veins in biotite quartz monzonite.	Two patented lode claims (Pocilio, Alma) total 29.54 acres. Adit 100 feet long on Pocilio claim. Idle 1958.
28	Redbird Lode and Blanche Placer	SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 29, T. 3 N., R. 1 E., S.B.M., at the north edge of Upper Holcomb Valley, 3 miles north of Big Bear Lake Ranger Station.	Undetermined, 1958; Al Bruning, 212 North Sullivan, Santa Ana (1956).	Northwest-trending quartz veins in biotite quartz monzonite. Older alluvium in Upper Holcomb Valley borders the monzonite on the south.	Redbird Lode claim developed by adit. Blanche Placer claim explored by two trenches 40 and 20 ft. long, 10 ft. wide and 5 to 10 ft. deep. Idle 1958.
29	Reservoir	SE $\frac{1}{4}$ sec. 36, T. 3 N., R. 1 W., SW $\frac{1}{4}$ sec. 31, T. 3 N., R. 1 E., S.B.M., along the southwest margin of Holcomb Valley, 2 $\frac{1}{2}$ miles northeast of Fawnskin.	Kern Rock Company, c/o Alta Vista and Kentucky St., Bakersfield, 1958.	Area covered by Recent alluvium and older alluvium and gravels. Older alluvium consists chiefly of weathered granitic rocks in a matrix of sand and gravel.	Part of the Holcomb Valley gold placer area. This claim apparently was originally known as "Extension of Valley Consolidated Gold mine," 37.03 acres patented in 1896. Idle 1958.
30	Slap Jack	N $\frac{1}{2}$ sec. 32, T. 3 N., R. 1 E., S.B.M., along the northwest margin of Upper Holcomb Valley 3 $\frac{1}{2}$ miles northeast of Fawnskin.	W. G. Lacy, c/o Lacy Oil Tool Co., 973 N. Main St., Los Angeles 12, 1958.	Area covered by older alluvium and gravels, and Recent alluvium.	One patented placer claim, 12.55 acres. Holcomb Valley gold placer area. Originally part of the Valley Consolidated Group patented in the 1890s. Part of the Holcomb Valley Placer Co. operation 1933-41. Idle 1958.
	Valley Consolidated Group No. 1	Secs. 31, 32, T. 3 N., R. 1 E., S.B.M., sec. 36, T. 3 N., R. 1 W., S.B.M., in Holcomb Valley and Upper Holcomb Valley.	See remarks.	Area covered by older alluvium and gravels, and Recent alluvium.	Holcomb Valley gold placer area. Placer group of 428.42 acres patented to J. T. Griffin and G. C. Gardner, 1896. Included nine claims: Black Dog, Bullion, California, Chiquita, Croesus, Eagle, Greenwood, Hope, Last Chance. Patent survey No. 3055, Aug. 28, 1891, included three additional claims: Nevada, Vulture, and Slap Jack, but the total acreage was the same. Apparently the same area was earlier known as the Mohave Gravel mine. See individual claim names listed herein.
31	Wayne Placers	W $\frac{1}{2}$ sec. 8, T. 2 N., R. 1 E., S.B.M., half a mile northwest of Big Bear Lake Ranger Station.	W. S. Wayne, Box 103, Twentynine Palms, 1958.	Calcite and dolomite marble of the Furnace formation, covered with Recent alluvium in creek beds. Placer gold occurs in the alluvium in narrow washes.	Two placer claims (Mount Bertha, Conglomerate). Mr. Wayne has operated on a small scale since about 1914. Some nuggets have been found and panning still produces "color." In this one-man operation the alluvium is first put through a dry concentrator and the concentrates are then panned by hand. Mr. Wayne continued prospecting the claims during 1958.
32	Wild Rose	SE $\frac{1}{4}$ sec. 18, T. 3 N., R. 1 E., S.B.M., in Wild Rose Canyon, 7 $\frac{1}{2}$ miles southeast of Lucerne Valley.	Victorville Lime Rock Company, Victorville, 1958.	Irregularly cherty, dark dolomite marble of the Furnace formation. Reported to contain pockets of gold-bearing quartz with iron oxide.	Developed by two shafts each 100 ft. deep, about 200 ft. apart, and several adits, now mostly covered. Idle 1958.

GOLD—Continued

Map no.	Name of claim, mine, or group	Location	Owner (name, address)	Geology	Remarks and references
33	Wright	Secs. 16, 17, T. 3 N., R. 1 W., S.B.M., 5 miles northwest of Holcomb Valley, near top of north slope San Bernardino Mountains.	Undetermined, 1958. Alvin Linder, Box 264, Lucerne Valley (1952).	Quartz veins strike southwest and southeast in sheared hornblende quartz monzonite, locally mylonitized. Shears strike N. 78° E., dip 36° SE.	Two adits driven southwest and southeast along quartz veins. Production undetermined, but idle for years. A five-stamp mill on property long idle. (Wright and others 53:63t).
34	Undetermined	SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 5, T. 3 N., R. 1 W., S.B.M., on the north flank of the San Bernardino Mountains, 5 $\frac{1}{2}$ miles southwest of Lucerne Valley.	Undetermined, 1958.	Northwest-trending shear zone in hornblende quartz monzonite.	Developed by several pits. Idle 1958.
35	Undetermined	NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 5, T. 3 N., R. 1 W., S.B.M., on the north flank of the San Bernardino Mountains, 5 $\frac{1}{4}$ miles southwest of Lucerne Valley.	Undetermined, 1958.	Granite cataclasite.	Developed by several pits. No indication of ore. Idle 1958.
36	Undetermined	SE $\frac{1}{4}$ sec. 14, T. 3 N., R. 1 W., S.B.M., along the Crystal Creek Trail, 5 miles north of Fawnskin.	Undetermined, 1958.	Area of contact between biotite quartz monzonite and migmatite.	Contacts explored by several large adits. No indication of ore. Idle 1958.
37	Undetermined	SE $\frac{1}{4}$ sec. 4, T. 3 N., R. 1 E., S.B.M., on east side of Deep Canyon, 4 $\frac{1}{2}$ miles southwest of Lucerne Valley.	Undetermined, 1958.	Contact between small pendant of Furnace formation calcite and dolomite marble and granite cataclasite.	Adit, probably 100-200 ft. long, driven east along contact. Latest activity apparently was about 1933.
38	Undetermined	NW $\frac{1}{4}$ sec. 10, T. 3 N., R. 1 W., S.B.M., west of Dry Canyon, 5 $\frac{1}{2}$ miles southwest of Lucerne Valley.	Undetermined, 1958.	Thin veins of hematite and epidote occur in a small mass of hornblende gabbro. The veins are as much as 6 in. thick, strike N. 70° W., dip 20° SW.	Explored by pit 10 ft. deep. Idle 1958.
39	Undetermined	SW $\frac{1}{4}$ sec. 11, T. 3 N., R. 1 W., S.B.M., east of Dry Canyon, 6 miles south, southwest of Lucerne Valley.	Undetermined, 1958.	Sheared zones in granite cataclasite.	Principal shears trend northwest and dip 30° SW. Shears are stained red-brown and yellow-brown with iron oxide, but no indication of vein material or ore. Explored by five adits, driven southwest and trending from N. 60° E. to N. 80° E., and one shaft inclined 30° SW. Adits apparently 50 to 200 ft. long. Idle 1958.

LEAD-ZINC-COPPER

40	Arctic Canyon	NW $\frac{1}{4}$ sec. 16, T. 3 N., R. 1 E., S.B.M., on the west side of Arctic Canyon, 7 $\frac{1}{2}$ miles southeast of Lucerne Valley.	Undetermined, 1958; A. A. Fairchild, Box 932, Los Angeles 53 (1952).	Well-bedded zone of fine-grained, buff-colored diopside-idocrase-quartz hornfels 10 ft. thick. Conformable to the south with black limestone of the Furnace formation which strikes N. 60° W., dips 80° S. Conformable to the north with 6-ft. dike of biotite quartz monzonite.	Hornfels explored by adit driven west about 5 ft. with 5-ft. shaft at end. Owner reports showings of lead, zinc, and copper. No indication of ore materials seen when visited in 1952. Idle 1958.
41	Nett	NW $\frac{1}{4}$ sec. 17, T. 3 N., R. 1 E., S.B.M., on a steep ridge east of Bousic Canyon, 7 miles southeast of Lucerne Valley.	Fred H. Nett, 435 Ash Street, Redlands, 1958.	Dolomite marble of the Furnace formation reported to contain pockets of lead and zinc carbonate ore minerals.	Locally believed to have been worked by Mexicans about 1830 for silver. Developed by a large shaft inclined 45° S., about 100 ft. deep, and several adits, now caved. Idle 1958.

LEAD-SILVER

	Silver Tip	Sec. 30, T. 3 N., R. 1 E., S.B.M.; not verified, 1958.	Undetermined, 1958. W. B. Calhoun, 1112 West 77th St., Los Angeles (1937). Operator: M. C. Knapp, 156 Magnolia Ave., San Bernardino (1937).	Pendants of Furnace formation calcite and dolomite marble, intruded by granite porphyry and biotite quartz monzonite.	May be same as no. 42. Reported developed by open cut. Ore shipped to smelter in 1937 contained 21.43 percent lead and 20.50 oz. of silver per ton. (Goodwin 57:670).
42	Undetermined	SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 30, T. 3 N., R. 1 E., S.B.M., at the north edge of Holcomb Valley, 3 $\frac{1}{2}$ miles northeast of Fawnskin.	Undetermined, 1958.	Blue-gray Furnace formation calcite marble contains zone 10 ft. wide of tremolite-calcite hornfels in 2- to 4-in. layers with calcite marble.	May be same as Silver Tip, which see herein. Developed by two shafts, each 15 ft. deep and 20 ft. apart. Drift driven north from bottom of northernmost shaft. Also open cuts. Idle 1958.

MANGANESE

Map no.	Name of claim, mine, or group	Location	Owner (name, address)	Geology	Remarks and references
43	Echo	NE¼SE¼ sec. 12, T. 3 N., R. 1 W., S.B.M., west of Furnace Canyon in the north foothills of the San Bernardino Mountains, 6 miles southeast of Lucerne Valley.	E. B. Mogle, 11240 Linden Street, Lynwood, 1958.	Pendant of white calcite and dolomite marble of the Furnace formation intruded by biotite quartz monzonite. Thin coatings of pyrolusite occur in nearly vertical fractures in the marble.	Short adit driven southwest at N. 80° E., explores a shear-zone contact between biotite quartz monzonite and white calcite marble. Several other short adits explore similar contacts, reported to contain showings of scheelite and manganese. Idle 1958.

TUNGSTEN

44	Undetermined	SW¼ sec. 16, T. 3 N., R. 1 E., S.B.M., on a steep ridge east of Arctic Canyon, 1¼ miles northeast of John Bull Flat.	Undetermined, 1958.	Scheelite-tremolite-idoerose-garnet-tactite in Furnace formation dolomite occurs near the contact with a graphophytic variant of biotite quartz monzonite. The ultraviolet lamp indicates about 1 percent scheelite in the tactite in an area about 3 by 5 ft. exposed in a small pit.	Developed by shallow prospect pit. Idle 1958.
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CLAY

45	Cushenbury Clay	NW¼ sec. 9, T. 3 N., R. 1 E., S.B.M., on the bluff along the west side of lower Arctic Canyon, 6½ miles southeast of Lucerne Valley.	Kaiser Steel Corporation, P.O. Box 217, Fontana, 1958.	Lenticular conglomerates, coarse sandstones, and less abundant mudstones of the Tertiary Old Woman sandstone formation crop out west of Arctic Canyon. This series of poorly bedded rocks has a minimum thickness of about 300 ft. The upper part of the formation consists of sub-rounded pebbles, averaging about 3 in. in diameter, contained in a coarse sandy matrix that comprises 50 percent of the rock. About half the larger particles are marble; the remainder include, in order of decreasing abundance, biotite quartz monzonite, quartzite, and vesicular volcanics. Toward the base of the formation where the grain size is finer, thin mudstone lenses intercalate the sandstone. The relative abundance of marble pebbles increases upward.	West of Arctic Canyon mudstone lenses, which contain quartzite pebbles and cobbles, are quarried to furnish part of the "clay" fraction (source of alumina, silica, iron) for the Cushenbury plant of the Permanente Cement Company. The area being quarried contains pebbles and cobbles of quartzite which are beneficial as they reduce the alkali content. The clay is reported to average 3 to 4 percent alkali and about 16 to 18 percent Al ₂ O ₃ . Mining is done by tractor-loader which loads end-dump trucks for transport to the plant. Active 1958.
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LIMESTONE

46	Carriere Limestone	Secs. 14, 15, 22, 23, 24, 26, T. 3 N., R. 1 W., S.B.M., and secs. 19, 30, T. 3 N., R. 1 E., S.B.M., 4 miles north of Fawnskin.	Undetermined, 1958; W. A. Carriere, Glenn, (1957).	Area is underlain mostly by Furnace formation calcite and dolomite marble, but is intruded by biotite quartz monzonite, hornblende quartz monzonite and granite porphyry.	At least 23 association placer claims were located during 1957. Part of the area contains white calcite marble, but much of the area is gray dolomite marble or intrusive rock. Analyses by Abbot A. Hanks, Inc., San Francisco, Sept. 1959, of 23 composite 10 to 20 ft. chip samples collected by the owners from rock in place averaged 46.83 percent CaO. The CaO ranged from 20.01 to 55.87 percent. Idle 1958.
47	Cushenbury	Secs. 15, 16, 17, T. 3 N., R. 1 E., S.B.M., across Arctic and Marble Canyons, 8 miles southeast of Lucerne Valley. Also large adjoining holdings outside the map area.	Kaiser Steel Corporation, P.O. Box 217, Fontana, 1958.	Large masses of calcite and dolomite marble of the Furnace formation strike northwest. In places the carbonate rocks are intruded by biotite quartz monzonite, have been faulted, and are covered by landslide material.	These carbonate rocks are unquarried, but constitute very large reserves for the Permanente Cement Company, Cushenbury Plant, located in the SW¼ sec. 11, T. 3 N., R. 1 E., S.B.M., about 1 mile east of the mapped area. In 1958 the plant was supplied with limestone quarried from the NW¼ sec. 14, T. 3 N., R. 1 E., S.B.M., on the west margin of Cushenbury Canyon.

LIMESTONE—Continued

Map no.	Name of claim, mine, or group	Location	Owner (name, address)	Geology	Remarks and references												
48	Golden Eagle Placer	S½SE¼ sec. 5, N½NE¼ sec. 8, T. 3 N., R. 1 W., S.B.M., on the west side of Silver Creek, 6 miles southwest of Lucerne Valley.	Victorville Lime Rock Company, Victorville, 1958.	Pendants of Furnace formation calcite and dolomite marble in migmatites of biotite quartz monzonite.	Patented 160-acre placer claim. Developed by roads and open cuts. No known production.												
49	Lucerne Valley Division, Victorville Lime Rock Company	Secs. 7, 17, 18, 19, 20, T. 3 N., R. 1 E., S.B.M., sec. 24, T. 3 N., R. 1 W., S.B.M., along Furnace and Wild Rose Canyons on the north slope of the San Bernardino Mountains, 7 miles southeast of Lucerne Valley.	Victorville Lime Rock Company, Victorville, 1958.	White calcite marble and white and gray dolomite marble of the Furnace formation crop out over much of the property. The carbonate rocks have been locally intruded by biotite quartz monzonite. A large mass of medium-grained, white calcite marble crops out on the north side of the lower part of Wild Rose Canyon.	Property includes Furnace placers 1-13 and White Rose placers 1-17, located in 1956 and totaling about 600 acres; part of the claims on east side of Furnace Canyon are patented; sec. 7 is owned in fee. During 1956-58 the property was under active development including extensive road building, sampling, and core drilling. In July 1958, a mill for grinding limestone for crushed industrial limestone products was under construction in the NE¼ sec. 7, on the west side of Bousic Canyon. Analysis by Pittsburgh Testing Laboratory, San Francisco, June 1959, of one sample collected by the writer from NW¼-SE¼ sec. 18, T. 3 N., R. 1 E., S.B.M., was as follows: <table><tr><td>CaO</td><td>SiO₂</td><td>Fe₂O₃</td></tr><tr><td>55.50%</td><td>0.31%</td><td>0.014%</td></tr><tr><td>Al₂O₃</td><td>MgO</td><td>P₂O₅</td></tr><tr><td>0.25%</td><td>0.42%</td><td>0.51%</td></tr></table> See table 1, samples 8, 9 for additional analyses in the area. Active development 1958, but no production as of July.	CaO	SiO ₂	Fe ₂ O ₃	55.50%	0.31%	0.014%	Al ₂ O ₃	MgO	P ₂ O ₅	0.25%	0.42%	0.51%
CaO	SiO ₂	Fe ₂ O ₃															
55.50%	0.31%	0.014%															
Al ₂ O ₃	MgO	P ₂ O ₅															
0.25%	0.42%	0.51%															
	Old Glory No. 4	SE¼ sec. 6, T. 2 N., R. 1 E., S.B.M., 1½ miles north of Big Bear Lake, east side of Poligue Canyon. Not verified, 1958.	G. T. Metcalf, Rt. 1, Box 601, Sonora, 1959.	Pendants of white, fine-grained Furnace formation calcite and dolomite marble.	No known production.												

DOLOMITE

50	Poligue Canyon	Sec. 7, T. 2 N., R. 1 E., S.B.M., astride Poligue Canyon, 1½ miles east of Fawnskin.	Undetermined, 1958; Richard Ormond et al., 11325 W. Washington Blvd., Los Angeles 66 (1957).	Pendants of Furnace formation dolomite marble intruded by biotite quartz monzonite and hornblende quartz monzonite.	Three unpatented association placer claims (Vulture, Madison, Gail). Idle, 1958.												
51	Sentinel Mining Company	Sec. 18, T. 3 N., R. 1 E., S.B.M., secs. 13, 24, T. 3 N., R. 1 W., S.B.M., along the west side of Furnace Canyon on the north slope of the San Bernardino Mountains, 7 miles south, southeast of Lucerne Valley.	Sentinel Mining Company, c/o Wilbur C. Veale, 584 East H St., Colton, 1958.	Large pendants of white calcite and dolomite marble of the Furnace formation, intruded by biotite quartz monzonite and granite porphyry. Intrusive rocks reported by owner to contain radioactive material and limestone reported to contain small amounts of scheelite and lead ore minerals. There are several large masses of white, fine-grained dolomitic marble which contains clots and seams of white, fibrous tremolite.	Area prospected many years ago, apparently for metallic minerals; several old adits explore contacts of carbonate and intrusive rocks. Holdings include 31 lode claims totaling about 600 acres. Exploratory work in 1958 included extensive road building and sampling. Potential quarry site for white, fine-grained dolomite marble in the center of sec. 13 stripped over an area about 200 by 300 ft. Analysis by Pittsburgh Testing Laboratory, San Francisco, June 1959, of one sample collected by the writer from NW¼SE¼ sec. 13, T. 3 N., R. 1 W., S.B.M., was as follows: <table><tr><td>CaO</td><td>SiO₂</td><td>Fe₂O₃</td></tr><tr><td>30.70%</td><td>6.26%</td><td>0.043%</td></tr><tr><td>Al₂O₃</td><td>MgO</td><td>P₂O₅</td></tr><tr><td>0.92%</td><td>18.23%</td><td>0.060%</td></tr></table> See table 1, samples 1, 5 for additional analyses in the area. Active development was continuing in July 1958.	CaO	SiO ₂	Fe ₂ O ₃	30.70%	6.26%	0.043%	Al ₂ O ₃	MgO	P ₂ O ₅	0.92%	18.23%	0.060%
CaO	SiO ₂	Fe ₂ O ₃															
30.70%	6.26%	0.043%															
Al ₂ O ₃	MgO	P ₂ O ₅															
0.92%	18.23%	0.060%															

ROCK PRODUCTS (SAND AND GRAVEL)

Map no.	Name of claim, mine, or group	Location	Owner (name, address)	Geology	Remarks and references
52	El Ray and Irene Extension	S½ sec. 33, T. 3 N., R. 1 W., S.B.M., along Holcomb Creek, 3 miles northwest of Fawnskin.	Undetermined, 1958; Cecil Burton, P.O. Box 15, Fawnskin (1956).	Recent alluvium consisting of sand and gravel occurs in the bed of Holcomb Creek. The deposits range from 150 to 400 ft. in width.	Sand and gravel is mined from shallow pits along the creek. Mining is done by bulldozer and small power shovel. Small trucks transport the material to a screening plant at Fawnskin or to local users. Most of the material is used as roadmetal. Active 1958.

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